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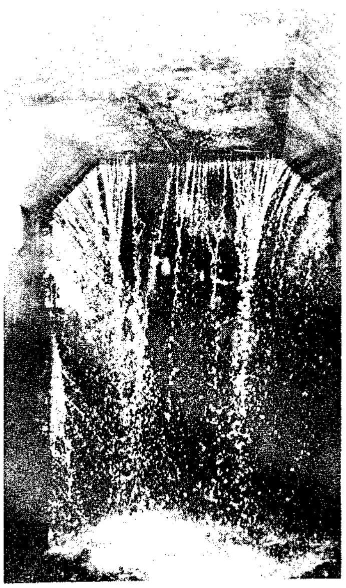

REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-CS-2

THE CONDITION OF CORPS OF ENGINEERS CIVIL WORKS CONCRETE STRUCTURES

by

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The following two letters used as part of the number designating technical reports of research published under the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program identify the problem area under which the report was prepared:

	Problem Area		Problem Area
CS	Concrete and Steel Structures	EM	Electrical and Mechanical
GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

For example, Technical Report REMR-CS-1 is the first report published under the Concrete and Steel Structures problem area.

COVER PHOTOS:

TOP—Spalled concrete of lock wall at John Day Lock and Dam, Columbia River, near The Dalles, Oregon. This deficiency, which has since been repaired, was considered severe enough to threaten the safety of the structure.

BOTTOM—"Carwash" effect, an example of excessive water leaking into the gallery due to waterstop failure, Little Goose Lock and Dam, Snake River, near Riparia, Washington.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Corps of Engineers currently operates and maintains 536 dams and 260 lock chambers at 596 sites. Sixty percent of these hydraulic structures are over 20 years of age, more than 40 percent are more than 30 years old, and approximately one-third are more than 40 years old. With the relatively limited number of new construction starts anticipated, many of these structures are being and will continue to be kept in operation well beyond their original design lives. The primary objective of this study was to develop quantitative

(Continued)

20. ABSTRACT (Continued)

information on the present condition of the concrete portions of these structures.

Two computerized data bases, (a) structure-description and (b) damage and repair, were compiled. The structure-description data base contains basic information (location, category, age, purpose, etc.) on 766 projects. The damage and repair data base contains information on the current condition of the concrete in the Corps' civil works structures as determined through detailed reviews of over 2000 periodic inspection reports.

To assist in the analysis, a number of computer programs were developed to manipulate and search the data bases. This analysis concentrated on the types of deficiencies observed, the cause (if reported), location within the structure, and degree of damage. Also, if the deficiency had been repaired, the material or technique or both that were used and the performance were analyzed.

This identification and assessment of problems relating to evaluation, maintenance, and repair of concrete will provide guidance in developing and establishing priorities for research in the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program.

PREFACE

The study reported herein was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), under Civil Works Research Work Unit 31553, "Maintenance and Preservation of Civil Works Structures," for which Mr. James E. McDonald is Principal Investigator. Funds for compilation of the structure-description data base and the review of periodic inspection reports were provided through the Concrete Research Program, for which Mr. Fred A. Anderson (DAEN-ECE-D) is Technical Monitor. Funds for compilation of the damage and repair data base and preparation of this report were provided through the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program, of which Messrs. John R. Mikel (DAEN-CWO-M), Tony C. Liu (DAEN-ECE-D), and Bruce L. McCartney (DAEN-CWH-D) are Technical Monitors.

The study was conducted at the US Army Engineer Waterways Experiment Station (WES) during the period January 1981 to March 1984 under the general supervision of Mr. Bryant Mather, Chief, Structures Laboratory; Mr. John M. Scanlon, Chief, Concrete Technology Division (CTD); and Mr. William F. McCleese, REMR Program Manager. Dr. Terence C. Holland was instrumental in the initial development of the structure-description data base. Mr. Joe G. Tom assisted in the review of periodic inspection reports. This report was prepared by Messrs. James E. McDonald and Roy C. Campbell, Sr.

Commanders and Directors of WES during the conduct of the study and the preparation and publication of this report were COL Nelson P. Conover, CE, COL Tilford C. Creel, CE, and COL Robert C. Lee, CE. Technical Directors were Mr. F. R. Brown and Dr. Robert W. Whalin.

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CONTENTS

THE CONDITION OF CORPS OF ENGINEERS CIVIL WORKS CONCRETE STRUCTURES

PART I: INTRODUCTION

Background

1. The Corps of Engineers currently operates and maintains 536 dams and 260 lock chambers at 596 sites. Sixty percent of these hydraulic structures are over 20 years of age, more than 40 percent are more than 30 years old, and approximately one-third are more than 40 years old. Nearly half of the 260 lock chambers along inland waterways will reach their 50-year design lives by the turn of the century. During this same period, annual waterborne traffic is expected to increase some 50 percent.* With the relatively limited number of new construction starts anticipated, many of these structures are being and will continue to be kept in operation well beyond their original design lives. Visits to these projects and review of periodic inspection reports have shown that many of the older structures require significant maintenance, repair, and rehabilitation. Furthermore, even the relatively new structures must be maintained and preserved to insure their efficient operation in the future.

Purpose

2. The primary objective of this study was to develop quantitative information on the condition of the concrete portions of the Corps' civil works structures. This information will provide guidance in developing and establishing research priorities in the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program.

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* J. Egan, D. Reitz, and E. Isely. 1982. "Evaluation of the Present Navigation System," final report prepared by A. T. Kearney, Inc., as part of the National Waterways Study conducted for the Institute for Water Resources, US Army Corps of Engineers, Ft. Belvoir, VA.

Scope

3. Engineer Regulation 1110-2-100* prescribes the procedures to be followed in periodically inspecting and evaluating those Corps civil works structures whose failure or partial failure would endanger the lives of the public or cause substantial property damage and impair the operational capability or serviceability or both of the structures. Since this inspection program was initiated in 1965, approximately 2500 formal reports have been generated. Of these reports, 2018 were available for this study, and each was reviewed in detail in an attempt to determine the condition of the concrete in the structures. The reviews concentrated on the types of deficiencies observed, the cause (if reported), location within the structure, and degree of damage. Also, if the deficiency had been repaired, the material or technique or both used and the performance were noted.

4. The information contained in the various reports varied widely, and in some cases, was followed up to obtain missing data or to clarify information. All data collected were compiled in a computerized data base, and appropriate search routines were developed to assist in the analysis.

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* Headquarters, US Army Corps of Engineers. 1983. "Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures," Washington, DC.

PART II: DATA BASE COMPILATION

5. Two data bases, (a) structure-description and (b) damage and repair, were compiled on the Honeywell DPS-1 computer at the Waterways Experiment Station (WES) to evaluate concrete damage and repair at Corps hydraulic structures. The structure-description data base contains basic information (location, category, age, purpose, etc.) on 766 projects. The source for most of these data was the Corps data base, COEDAM. Since a significant number of structures were not listed in COEDAM, additional information was obtained from various District offices and the annual reports on civil works activities of the Chief of Engineers. The damage and repair data base contains data codes that denote the observed deficiency, cause, location, and degree of damage as well as repair materials, techniques, and performance of repair. The primary sources for these data were Corps periodic inspection reports.

Computer Programs

6. Time-sharing programs were created to manipulate and search the data bases. Detailed descriptions of the programs are presented in Appendix A and summarized in the following:

Program	Execution Mode	Program Function
ACHECK	Time-sharing	Reads time-sharing files containing the structure-description data base and checks for coding errors
MB	Batch	Reads time-sharing files containing the structure-description data base, formats data, and writes formatted data to a saved tape
JCLCONT	Batch	Reads the saved tape from execution of program MB, reformats data into tables, writes tables to a saved tape, and directs output to the page printer
JCLPCONT	Batch	Reads the saved tape from execution of program JCLCONT and directs output to the page printer
SNAME	Time-sharing	Reads and compares structure names from pairs of District time-sharing files, one from the structure-description data base and the other from the damage and repair data base

Program	Execution Mode	Program Function
ICHECK	Time-sharing	Reads time-sharing files containing the damage and repair data base and checks for coding errors
DEFECTS	Batch	Reads time-sharing files containing the damage and repair data base, interprets codes into alpha descriptions, writes tables of inspection reports and tables of sums of damage and repair codes to a saved tape, and directs output to the page printer
PTAPE	Batch	Reads the saved tape from execution of program DEFECTS and directs output to the page printer
SEARCH	Time-sharing	Reads time-sharing files containing the damage and repair data base, searches data for strings of codes, and writes data for any matches found to a time-sharing output file
SEARCH2	Time-sharing	Reads time-sharing files output from execution of program SEARCH, SEARCH2, or SEARCH3; searches data for strings of codes; and writes data for any matches found to a time-sharing output file
SEARCH3	Time-sharing	Reads time-sharing files output from execution of program SEARCH, SEARCH2, or SEARCH3; searches data for range(s) of code(s); and writes data for any matches found to time-sharing output file

Program files are executed from time-sharing for batch mode by giving the command

JRN ROSC45/'File name',R

and for time-sharing mode by giving the command

FRN ROSC45/'File name',R

Coding of Data

7. To expedite analysis of the information in the 2018 periodic inspection reports reviewed, data codes were developed to denote observed deficiencies,

causes, locations, degree of damage, repair material, repair technique, and performance. These damage and repair codes are listed in Appendix B. As the inspection reports were reviewed, the appropriate codes were entered on data sheets in a manner similar to the following:

Deficiency				Repair		
Observation	Cause	Location	Degree of Damage	Material	Technique	Performance
125	270	337	403	530	642	704

These entries describe a longitudinal crack caused by settlement or movement in a stilling basin wall and classified as moderate damage. The crack had been repaired using an unspecified joint sealant applied by routing and sealing, and the repair performance was rated as poor. A data sheet for a typical inspection is included in Appendix B.

Terminology

8. In general, the terminology used here is in accordance with that prescribed in the 1978 American Concrete Institute Committee 116 report "Cement and Concrete Terminology." The deficiencies observed are defined in Appendix B. Since the terminology used in the inspection reports varied widely, photographs contained in those reports were valuable in efforts to compile available information on a more uniform basis.

Summary of Results

Observed deficiencies

9. A total of 10,096 deficiencies were identified during the review of available periodic inspection reports. Types of deficiencies observed and reported are shown in Table 1. The deficiencies are summarized in eight general categories in Table 2; totals were as follows:

Deficiency	Observations
Construction faults	229
Cracking	3,842
Disintegration	435
Distortion or movement	747
Erosion	642
Joint sealant failure	217
Seepage	2,048
Spalling	1,936
Total	10,096

Causes of observed deficiencies

10. In most instances, it was not possible to determine from the inspection reports the causes of observed deficiencies. There were only 1699 instances (about 17 percent of the total observations) in which a cause was reported. Causes reported are shown in Table 3 and summarized in Table 4. Totals were as follows:

Cause	Instances
Accidental loading	139
Chemical reactions	64
Construction faults	243
Maintenance faults	14
Corrosion	41
Design errors	52
Erosion	414
Settlement or movement	314
Shrinkage	249
Temperature	55
Weathering	114
Total	1699

Locations of observed deficiencies

11. Deficiencies were reported in 10,205 locations within Corps hydraulic structures. Locations are shown in Table 5 and are summarized according to type of structure in Table 6. Totals were as follows:

Location	Instances
Bridges	683
Dams	6,518
Navigation locks	2,227
Powerhouses	553
Other	224
Total	10,205

Degree of damage classifications

12. Where possible, the degree of damage due to the deficiency observed was assessed. The following definitions were used:

a. Light. A noticeable deficiency whose relative extent of damage is minor or superficial. No immediate remedial action is needed.

b. Moderate. A deficiency whose relative extent of damage is significant; a deficiency whose damage is light in degree and excessive in occurrence. Monitoring or remedial action or both may be required.

c. Severe. A pronounced deficiency whose relative extent of damage is excessive; a deficiency whose damage is moderate in degree and excessive in occurrence; monitoring or repair is required. A deficiency whose damage is of such a degree that the structural element being observed can no longer serve its design function; repair is required.

d. Threatens safety of structure. Deficiency such that if not remedied could result in the structure becoming inoperative or failing.

Examples of various observed deficiencies classified in accordance with these guidelines are included in Appendix C. Totals were as follows:

Degree of Damage	Instances
Light	6494
Moderate	2612
Severe	569
Threatens safety of structure	30
Total	9705

Repair materials and techniques

13. Repairs to alleviate approximately 900 deficiencies were identified in the review of inspection reports. Various repair materials (Table 7) and techniques (Table 8) were used. It was possible to rate the performance of these repairs (good, fair, poor, or failed) in approximately 600 cases.

PART III: DATA ANALYSIS

Observed Deficiencies

14. The 10,096 observed deficiencies in Table 1 are grouped according to Corps Divisions in Table 9. The observed deficiencies can be summarized as follows:

Division	Light	Moderate	Severe	Threatens Safety of Structure	Overall
Lower Mississippi Valley (LMVD)	288	289	111	7	781
Missouri River (MRD)	749	252	12	0	1,042
North Atlantic (NAD)	362	117	7	2	502
North Central (NCD)	531	400	116	10	1,080
New England (NED)	476	96	16	0	593
North Pacific (NPD)	637	329	46	3	1,113
Ohio River (ORD)	1309	583	185	2	2,141
South Atlantic (SAD)	455	235	38	6	746
South Pacific (SPD)	423	100	16	0	559
Southwestern (SWD)	1264	211	22	0	1,539
Total	6494	2612	569	30	10,096

The number of deficiencies reported per Division (Figure 1) ranged from 502 by NAD to 2141 by ORD. These two Divisions also represent the extremes in numbers of structures, 25 and 147 for NAD and ORD, respectively. There appears to be a general correlation between the number of structures in a given Division and the number of observed deficiencies (Figure 2).

15. There was no apparent correlation between the average age of structures within a given Division and the number of overall deficiencies observed (Figure 3). This lack of correlation is attributed in part to the large number of observed deficiencies classified as light damage. These minor deficiencies, representing approximately 65 percent of the total, might be expected to occur at any time during the life of a structure. However, considering only those deficiencies classified as severe damage or threatens safety of structure, there appears to be a general trend toward an increased number of these deficiencies as the average age of the structures increases (Figure 4). This would indicate that, as Corps structures remain in service and their average age increases, the number of deficiencies requiring repair will increase.

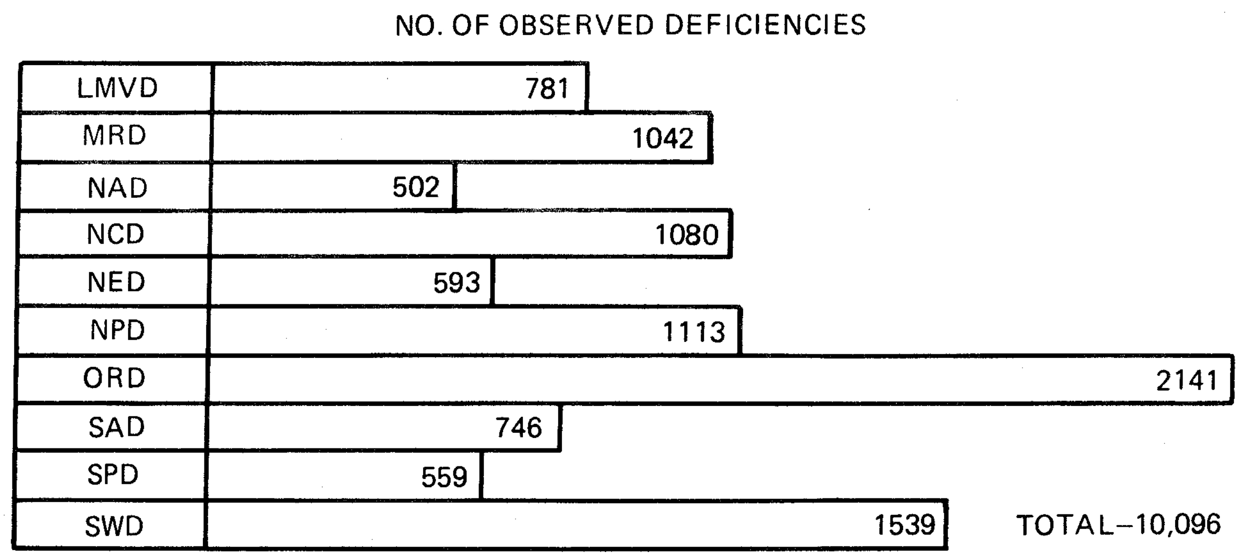


Figure 1. Number of deficiencies observed and reported by Corps Divisions

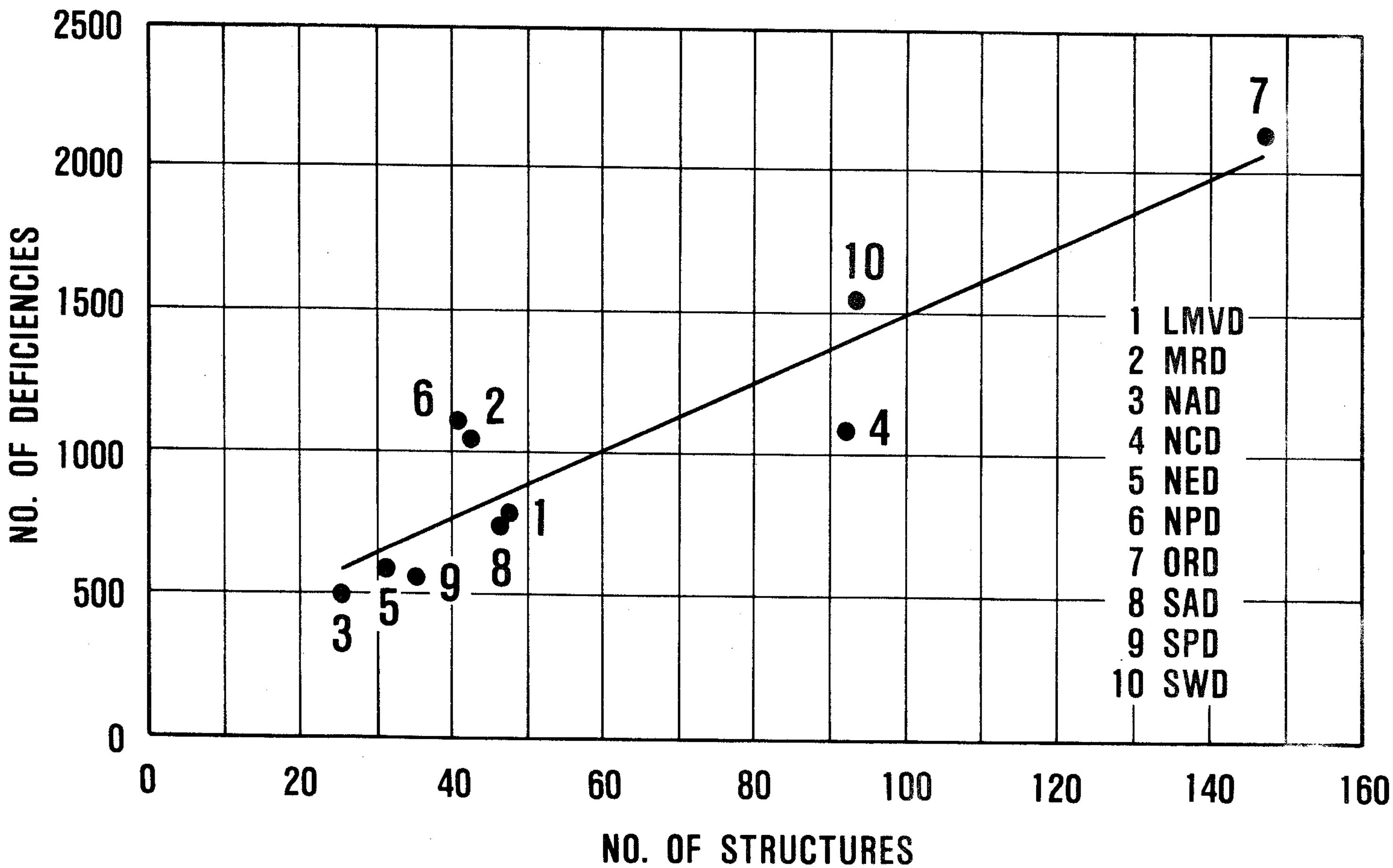


Figure 2. Relationship between number of observed deficiencies and number of structures within Corps Divisions

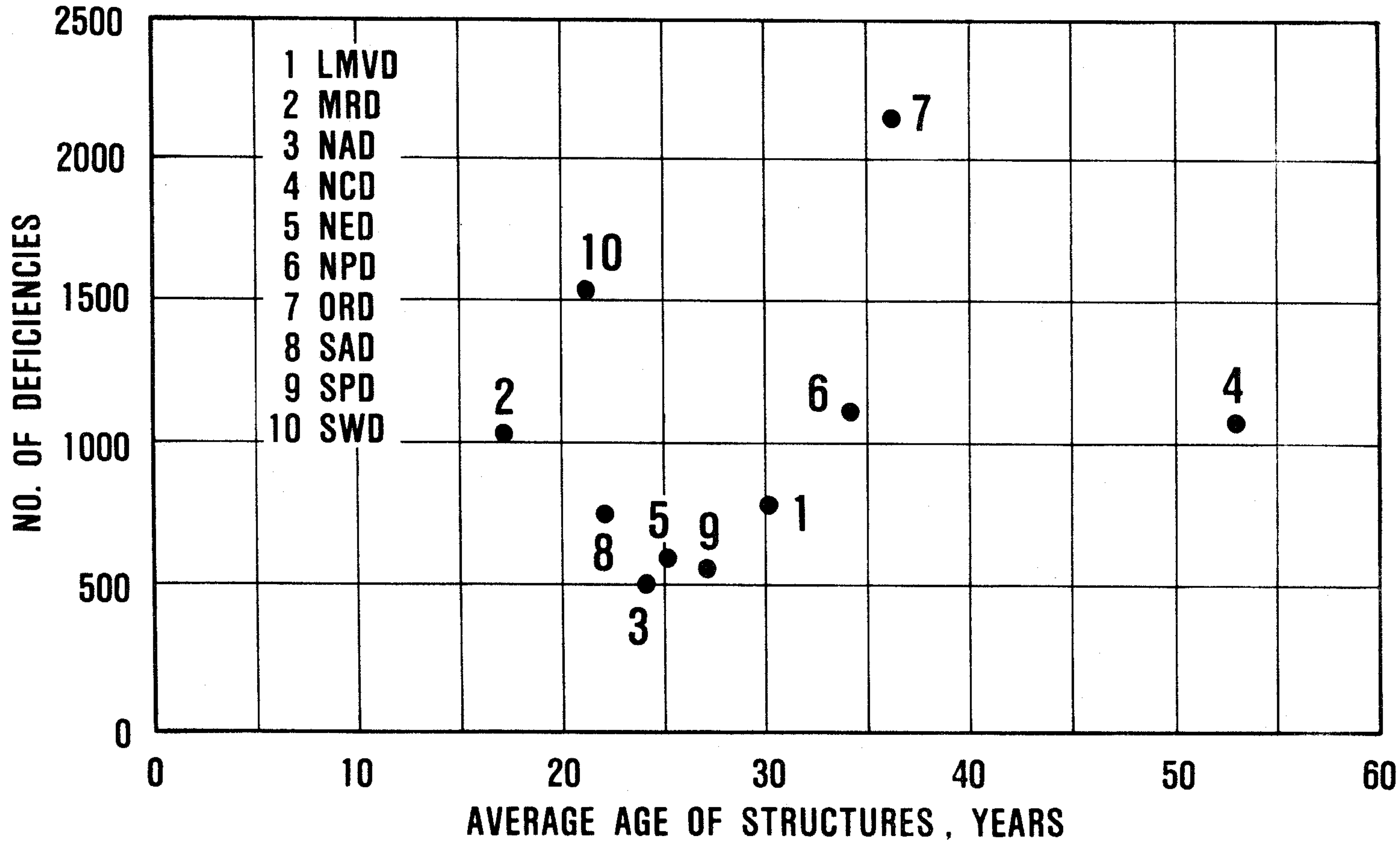


Figure 3. Relationship between total number of deficiencies reported and average age of structures within Corps Divisions

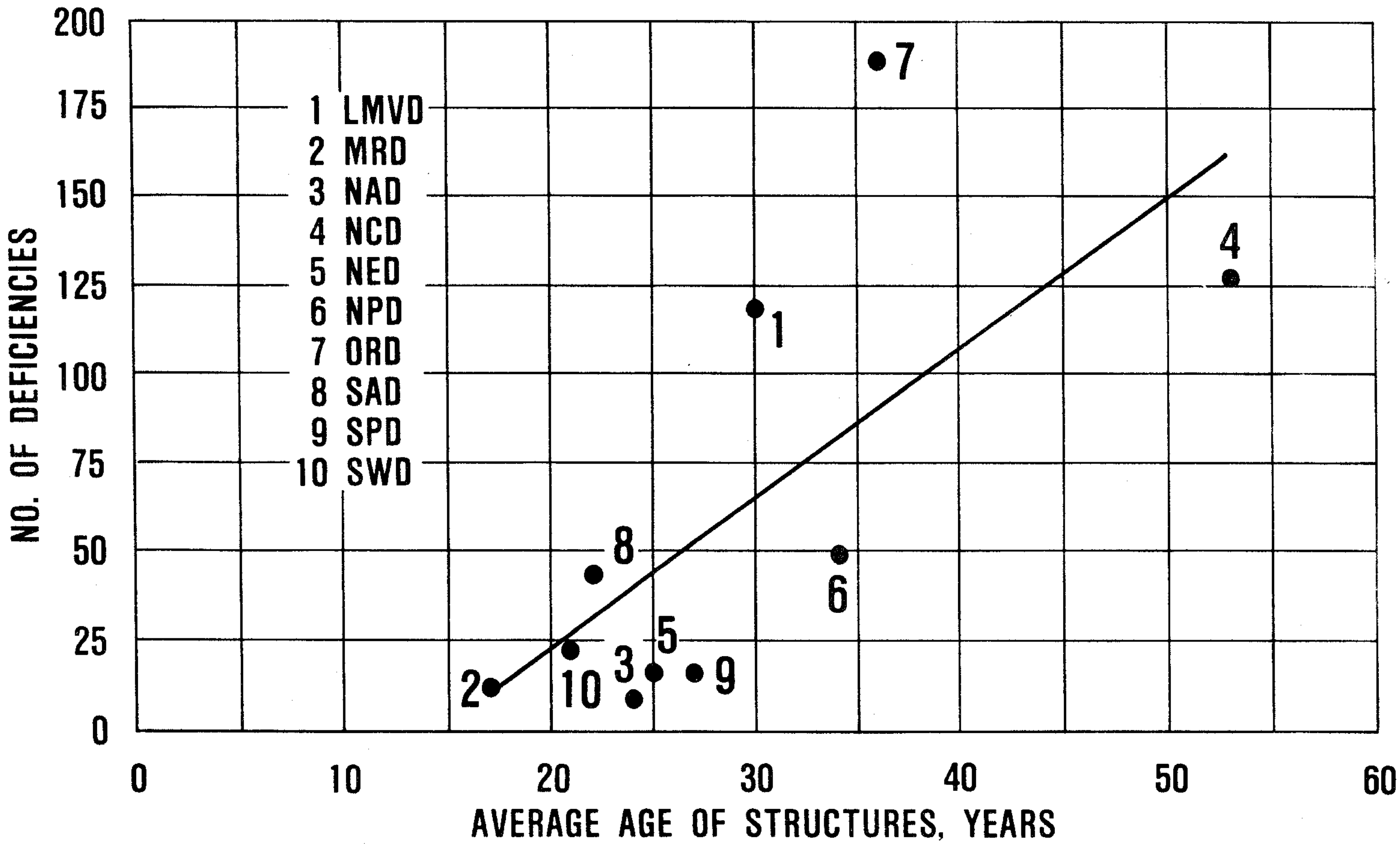


Figure 4. Relationship between number of deficiencies classified as either severe or threatens safety of structure and average age of structures within Corps Divisions

16. The total of 10,096 deficiencies amounts to approximately 17 deficiencies for each lock or lock and dam project owned and operated by the Corps in 1984. The total number of deficiencies is probably somewhat less than 10,096 since a given deficiency may have been observed and reported in more than one inspection report for a given structure. However, since the primary objective of this analysis is to identify trends in problems relating to maintenance and repair of hydraulic structures, the information obtained from the 2018 inspection reports is believed to be an adequate sample.

17. Types of observed deficiencies are shown in Table 1 and summarized in Table 2. Concrete cracking was the deficiency most often observed (Figure 5). Other major problem areas based on number of deficiencies were seepage and spalling, which accounted for 20 and 19 percent of the total, respectively.

Cracking

18. Concrete cracking was the deficiency most often observed (3842 cases), regardless of degree of damage (Figure 6). Deficiencies related to cracking, as a percentage of the total deficiencies within a given degree of damage classification, were somewhat erratic (Figure 7), ranging from 25 to 42 percent of the deficiencies classified as severe and moderate, respectively, as compared to 38 percent overall (Figure 5). Of the 3719 cases in which cracking was noted as a deficiency and it was possible to classify as to degree of damage, 96 percent were either light or moderate damage. Concrete cracking of this degree, while in itself not generally detrimental to a structure other than aesthetically, can lead to other more serious problems. For example, moisture intrusion through such cracks can cause the concrete to become critically saturated. Non-air-entrained concrete subjected to freezing and thawing while critically saturated will suffer significant deterioration. It should be noted that, of the Corps' 186 structures which are more than 40 years old, more than 70 percent are located in NCD and ORD, areas of relatively severe exposure to freezing and thawing. This factor emphasizes the need for reliable materials and effective techniques to maintain these structures to prevent progressive deterioration.

19. Concrete cracking classified as either severe or threatens safety of structure, although only 4 percent of the cracking deficiencies, accounted for 25 percent of the total deficiencies within these two damage classifications. Thus, in addition to the need for maintenance methods to deal with concrete cracking, there is also a need for effective repair procedures.

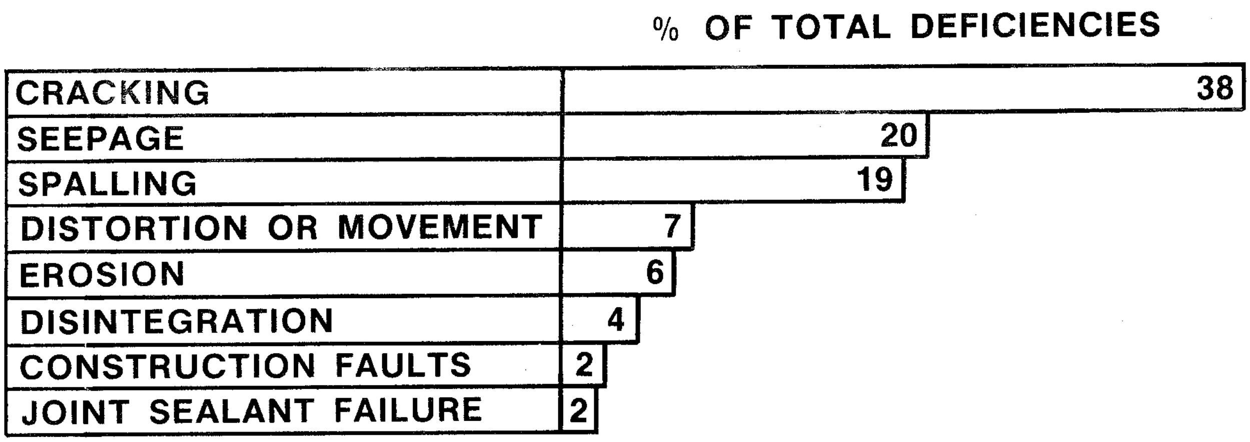


Figure 5. Percentage of total observed deficiencies for eight general categories of observed deficiencies

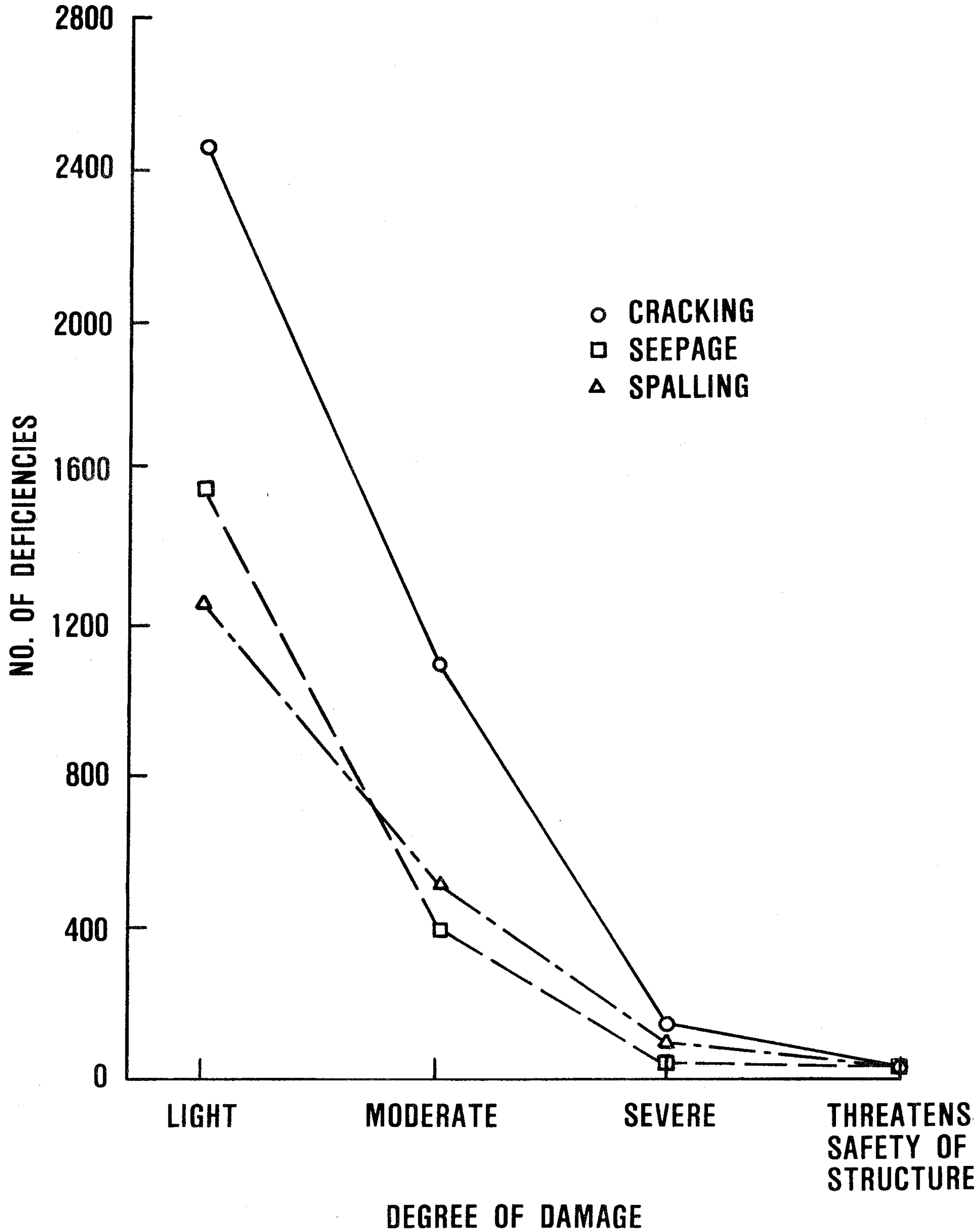


Figure 6. Relationship between number of cracking, seepage, and spalling deficiencies observed and their degree of damage

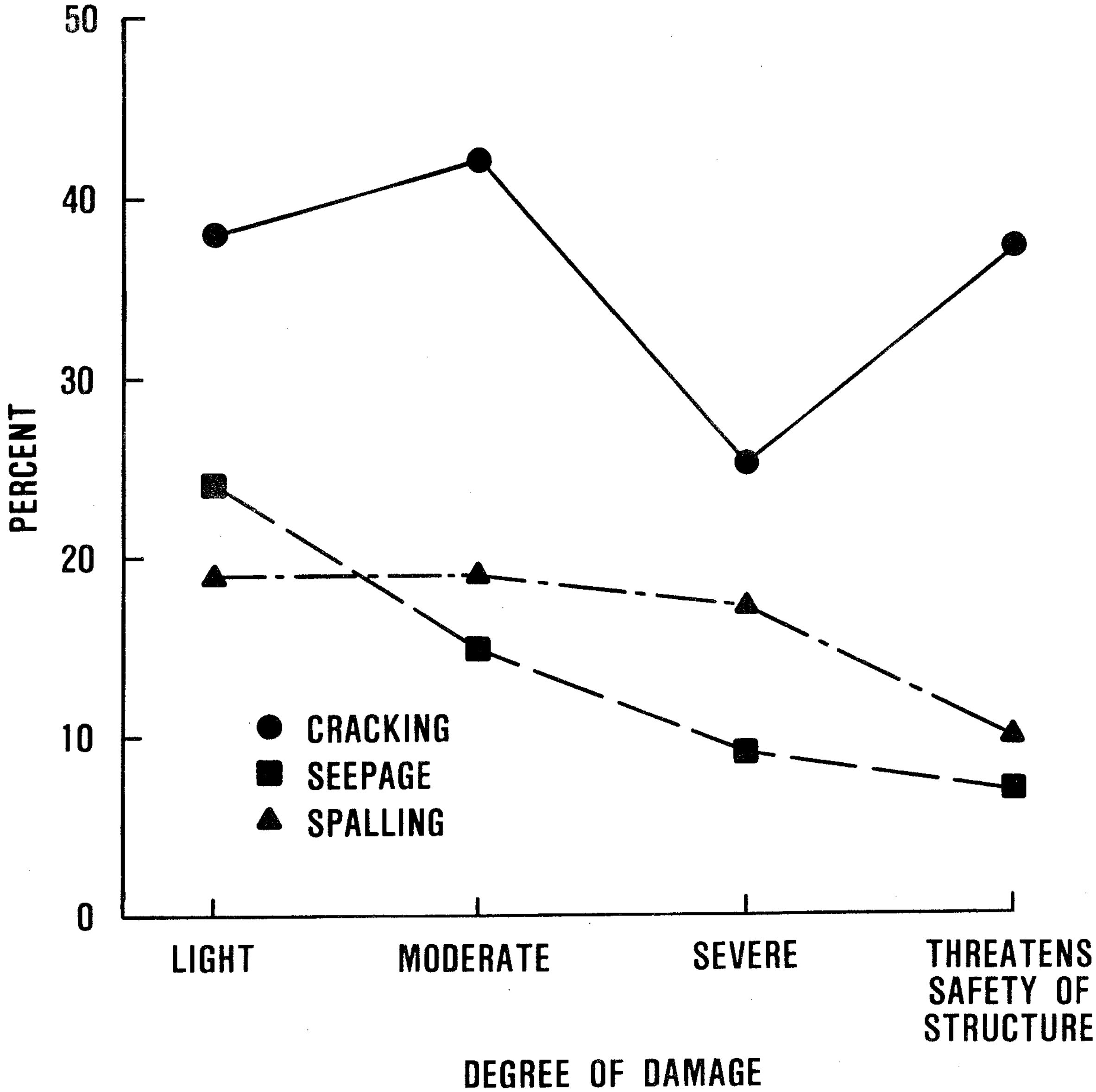


Figure 7. Percentage of total cracking, seepage, and spalling deficiencies within the various degree of damage classifications

20. During the review, attempts were made to classify concrete cracks according to width or direction (Table 1); however, this was possible for only 55 percent of the deficiencies. Improved procedures in inspection, evaluation, and classification of concrete cracking are needed.

Seepage

21. Seepage was the second most prevalent deficiency reported (2048 cases), accounting for 20 percent of the total deficiencies (Table 2). Whereas cracking as a percentage of the total deficiencies within a given degree of damage classification was somewhat erratic, seepage deficiencies steadily decreased both in number (Figure 6) and as a percentage of total deficiencies (Figure 7) as the degree of damage increased. In the 2005 cases in which it was possible to classify seepage according to degree of damage, 1950 of the deficiencies (97 percent) were either light or moderate damage.

22. Where possible, seepage was broken down into the more specific deficiencies (corrosion, etc.) shown in Table 1. However, in most cases (65 percent), it was not possible to determine the specific type of seepage. In those cases (726) where a specific manifestation of seepage was reported, efflorescence accounted for 75 percent of the deficiencies.

Spalling

23. Overall, 1936 cases of spalling were reported, amounting to 19 percent of the total deficiencies (Table 2). Spalling deficiencies decreased steadily in number as the degree of damage increased (Figure 6). However, as a percentage of the total deficiencies within a given degree of damage classification, spalling deficiencies were essentially constant (17 to 19 percent) for the light, moderate, and severe damage classifications, decreasing to 10 percent of the deficiencies classified as threatens safety of structure (Figure 7).

24. Although the total number of cracking deficiencies observed was approximately twice the number of spalling deficiencies, the number of structures involved in each case was much more nearly equal (Figure 8). For example, in the light damage classification, there were 2473 cracking deficiencies observed involving 494 structures as compared to 1258 spalling deficiencies involving 417 structures.

25. Where it was possible to classify spalling deficiencies as to degree of damage, the results were similar to those for cracking and seepage deficiencies; i.e., 95 percent were either light or moderate damage indicating a significant effort in the future relating to repair of concrete spalls.

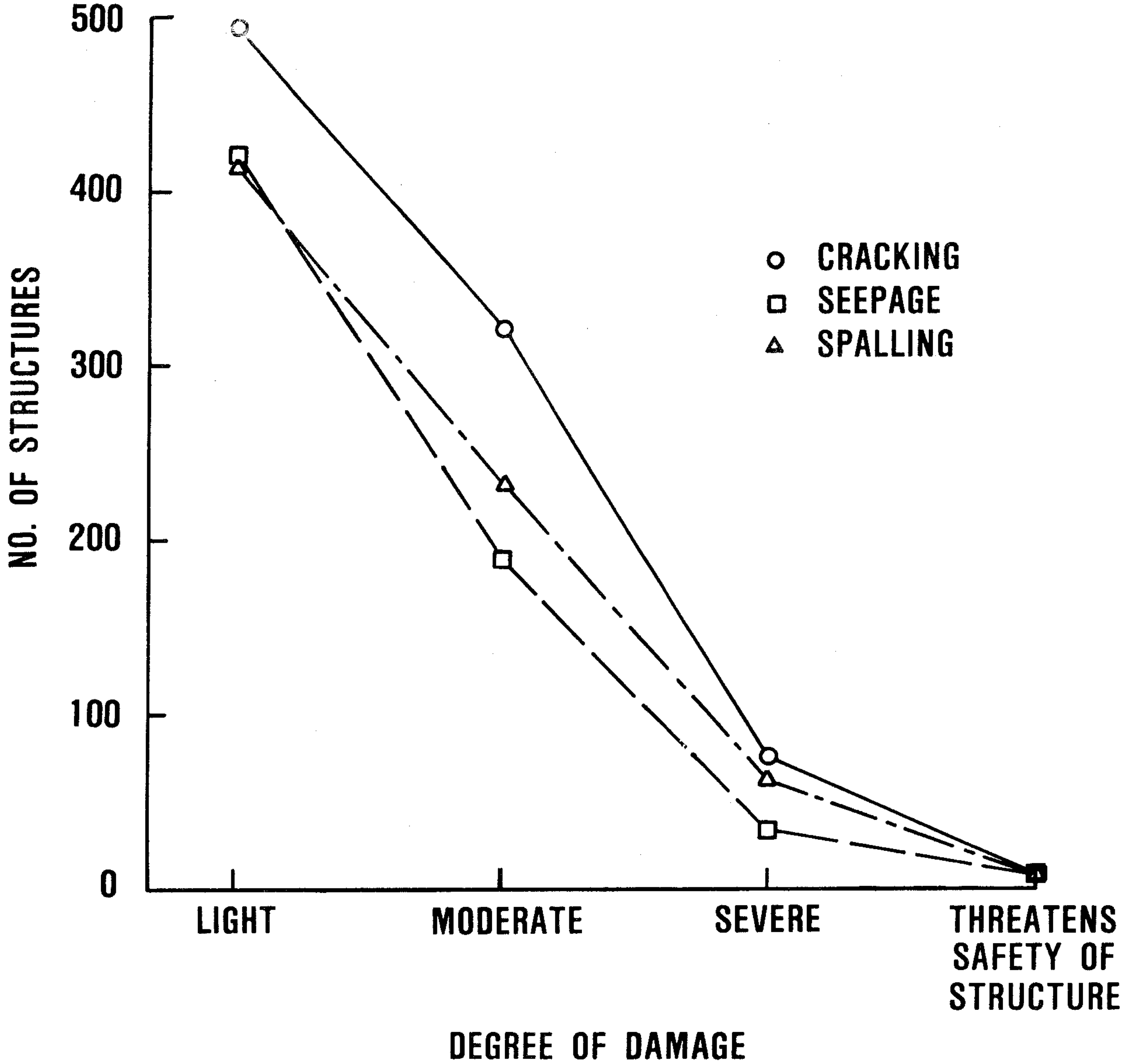


Figure 8. Relationship between number of structures with cracking, seepage, and spalling deficiencies and their degree of damage

Distortion or movement

26. There were 747 deficiencies reported relating to distortion or movement, which accounted for 7 percent of the total deficiencies observed (Table 2). Although the number of distortion or movement deficiencies decreased with increasing degree of damage (Figure 9), as a percentage of the total deficiencies within a given degree of damage classification, they increased as the degree of damage increased (Figure 10).

27. The type of distortion or movement was unspecified in 416 of the 747 cases reported (Table 1). In the remaining cases, settling accounted for 70 percent of the deficiencies. In those cases where the deficiency could be classified as to degree of damage, 90 percent were either light or moderate damage.

Erosion

28. There were 642 cases of erosion damage reported, which accounted for 6 percent of the total deficiencies reported (Table 2). The relationship between number of observed erosion deficiencies and degree of damage was very similar to that for distortion or movement deficiencies (Figure 9). There were no erosion deficiencies classified as threatens safety of structure. Eighty-eight percent of the erosion deficiencies classified according to degree of damage were either light or moderate damage. However, it should be noted that most structures are not dewatered at the time of their inspection. If they were, it is expected that this percentage would be higher.

29. The type of erosion was not specified in 74 percent of the cases reported. Given the relative ease in distinguishing between abrasion and cavitation-erosion, this shortcoming in the data appears to indicate a need for either more attention to detail in inspection reports or additional training for inspection personnel. In those cases where the type of erosion was specified, abrasion-erosion accounted for 54 percent of the deficiencies.

Disintegration

30. There were 435 cases of disintegration reported, which accounted for 4 percent of the total deficiencies (Table 2). Although the number of disintegration deficiencies decreased with increasing degree of damage (Figure 9), the numbers of deficiencies classified as light and moderate damage were nearly the same. Disintegration, as a percentage of the total deficiencies within a given degree of damage classification, generally increased with increasing severity of damage (Figure 10) though not as dramatically as distortion or movement deficiencies.

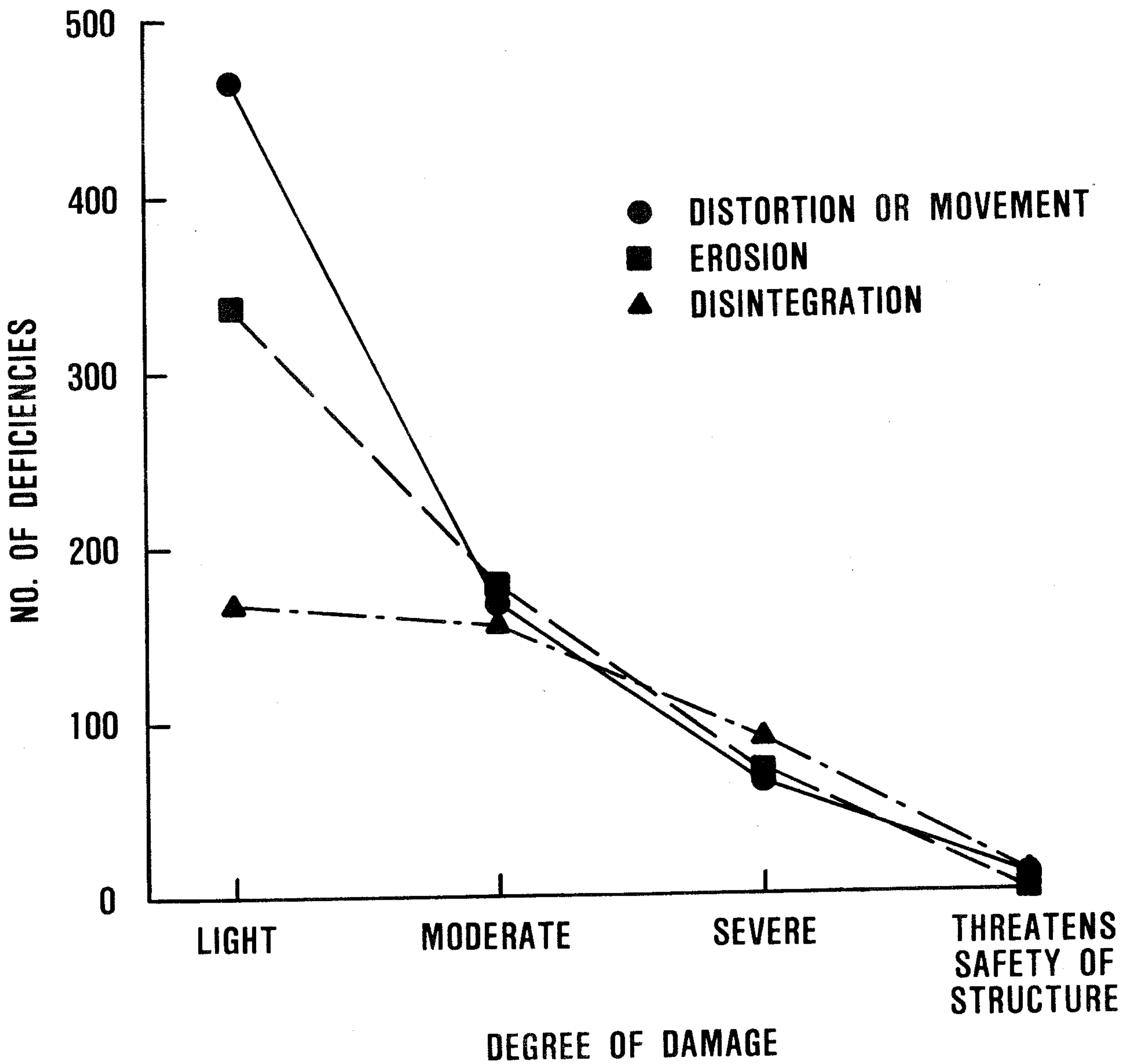


Figure 9. Relationship between number of distortion or movement, erosion, and disintegration deficiencies observed and their degree of damage

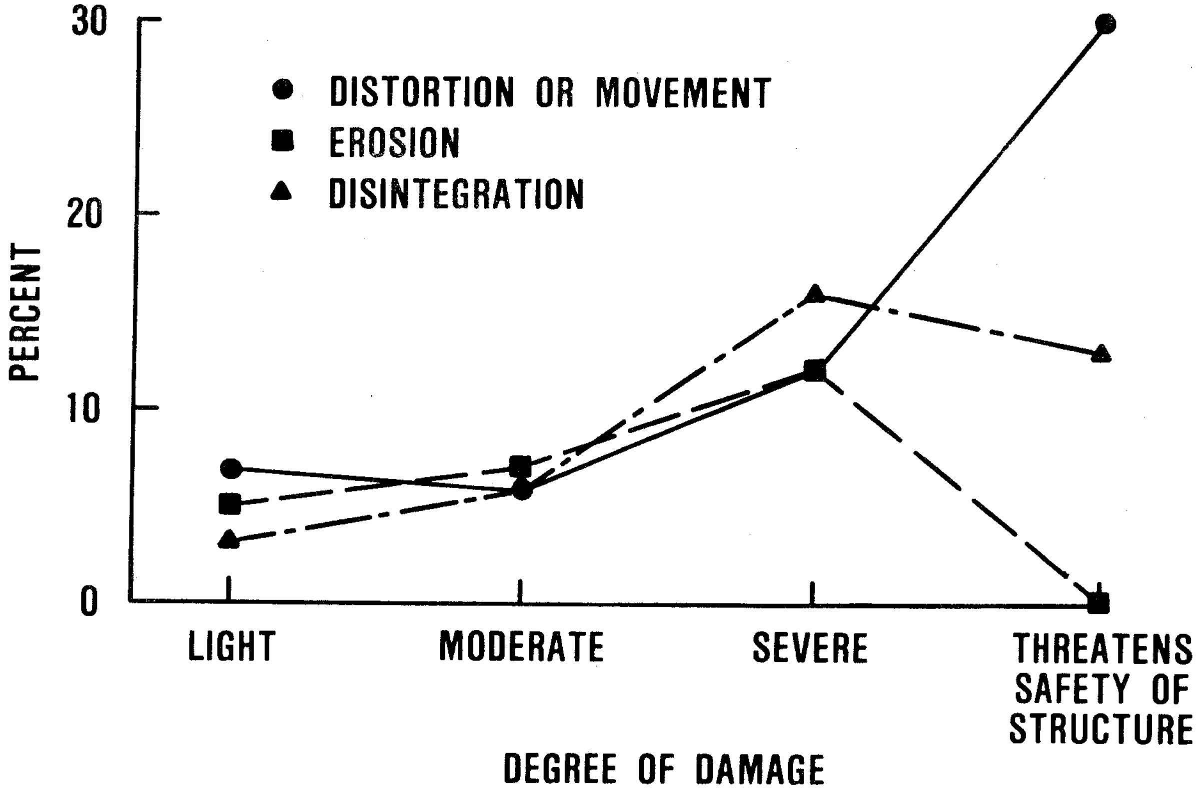


Figure 10. Percentage of total distortion or movement, erosion, and disintegration deficiencies within the various degree of damage classifications

31. The type of disintegration was specified in 266 (61 percent) of the cases. In most of these cases, either scaling or weathering was specified, accounting for 22 and 32 percent of the total disintegration deficiencies, respectively.

32. Disintegration deficiencies were classified according to degree of damage in 413 of the total 435 observations. In those cases, 77 percent of the total were classified as either light or moderate compared to 96 and 97 percent for cracking and seepage deficiencies, respectively. This difference would indicate that problems with concrete disintegration, though fewer in number than those related to cracking and seepage, are significantly more severe. Therefore, it would be expected that the emphasis in addressing problems involving disintegration would be on repair and rehabilitation as opposed to the maintenance activities required in the majority of cracking and seepage problems.

Construction faults

33. There were 229 construction faults reported, which accounted for 2 percent of the total deficiencies (Table 2). Most of these deficiencies, 172 cases involving 112 structures, were classified as light damage. The type of construction fault was specified in 88 percent of the cases (Table 1). The construction fault most frequently observed was irregular surface, which accounted for 45 percent of the specified deficiencies.

Joint sealant failure

34. There were 217 observations of joint sealant failure, accounting for 2 percent of the total deficiencies (Table 2). This was the only deficiency for which the largest number of cases was not classified as light damage. Of the 203 deficiencies classified according to degree of damage, 100 (49 percent) were classified as moderate damage compared to 30 and 21 percent for light and severe damage, respectively.

Causes of Observed Deficiencies

35. During the review of inspection reports, it was possible to determine causes of the observed deficiencies in only 1699 instances out of the total of 10,096 deficiencies observed and reported. Granted, there are situations in which detailed investigations involving nondestructive testing, core drilling, laboratory testing, etc., are required to ascertain the cause of concrete deterioration and such activities are normally beyond the scope of a periodic

inspection. However, it would appear that investigations of this nature would not have been required in a significant number of the more than 8000 instances in which a cause was not reported. This would appear to indicate a need for improved evaluation procedures. Also, additional training of inspection personnel in visual evaluation and classification of concrete condition and increased attention to detail in reporting procedures may be needed.

36. Causes reported for the observed deficiencies are shown in Table 3 and summarized according to general category of cause in Table 4. In each case, the overall total for each cause is shown; also, the causes are shown in relation to the degree of damage assigned to the resulting deficiency. Cause-deficiency relations are shown in Tables 10-13 for the various degrees of damage and are summarized in Table 14.

37. Erosion, settlement or movement, shrinkage, and construction faults, in that order, were most frequently reported as causes of the observed deficiencies. These four causes accounted for 71 percent of the total causes reported (Figure 11). This result is attributed, at least in part, to the fact that these causes could be relatively easily discerned visually.

38. Overall, causes were reported for only 17 percent of the total observed deficiencies. As might be expected, the more severe the damage, the more cases in which the cause of the deficiency was reported (Figure 12). However, even in those instances in which the severity of damage was such that repairs were required, causes were reported for only 31 and 50 percent of the deficiencies classified as severe and threatens safety of structure, respectively.

39. The percentage of causes reported for a given category of observed deficiency varied widely (Table 14). Construction faults and erosion were the deficiencies most easily diagnosed, with the causes of each being reported nearly 60 percent of the time (Figure 13). On the other hand, causes for seepage and joint sealant failure were reported for only 5 percent or less of the observed deficiencies. These results indicate a need for improved evaluation procedures in these areas.

Locations of Observed Deficiencies

40. Deficiencies were reported at the locations within Corps hydraulic structures shown in Table 5. In addition to the total number of deficiencies at each location, the locations are shown in relation to the degree of damage

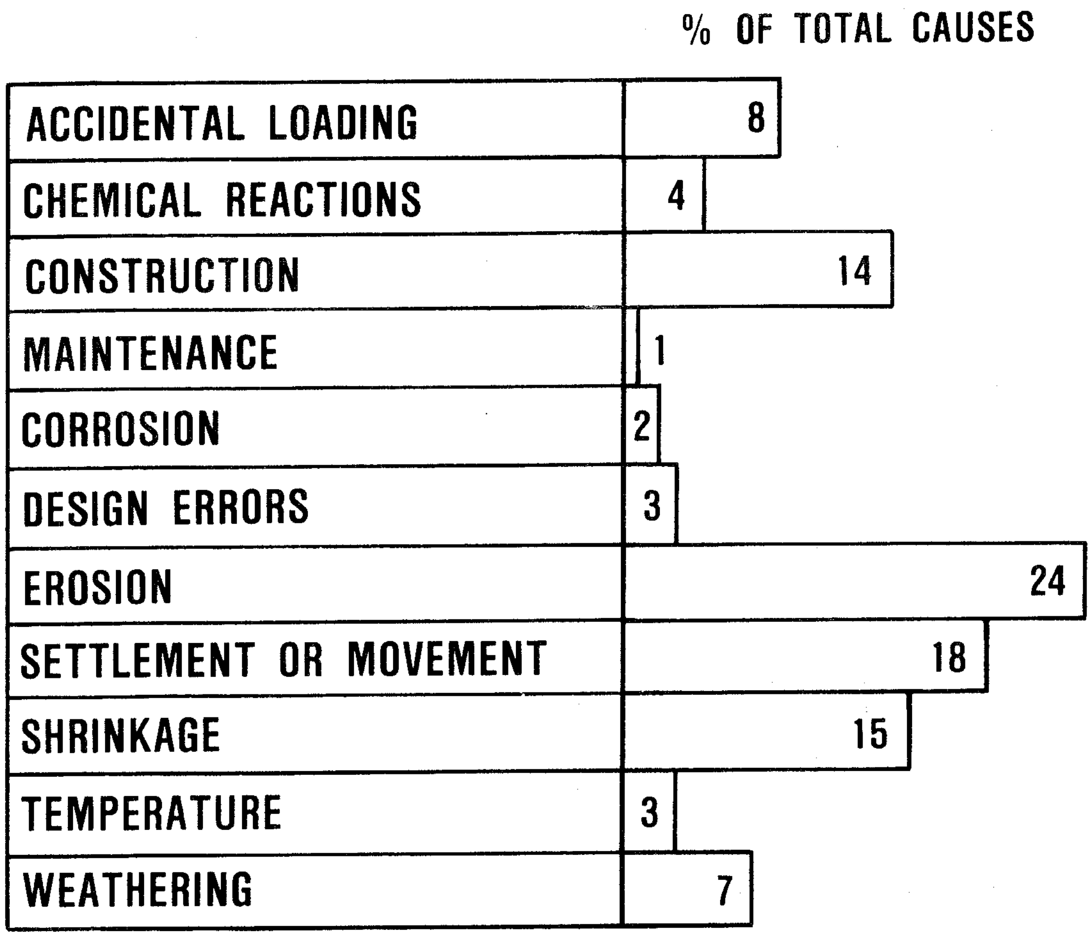


Figure 11. Percentage of total causes of observed deficiencies for 11 general categories of causes

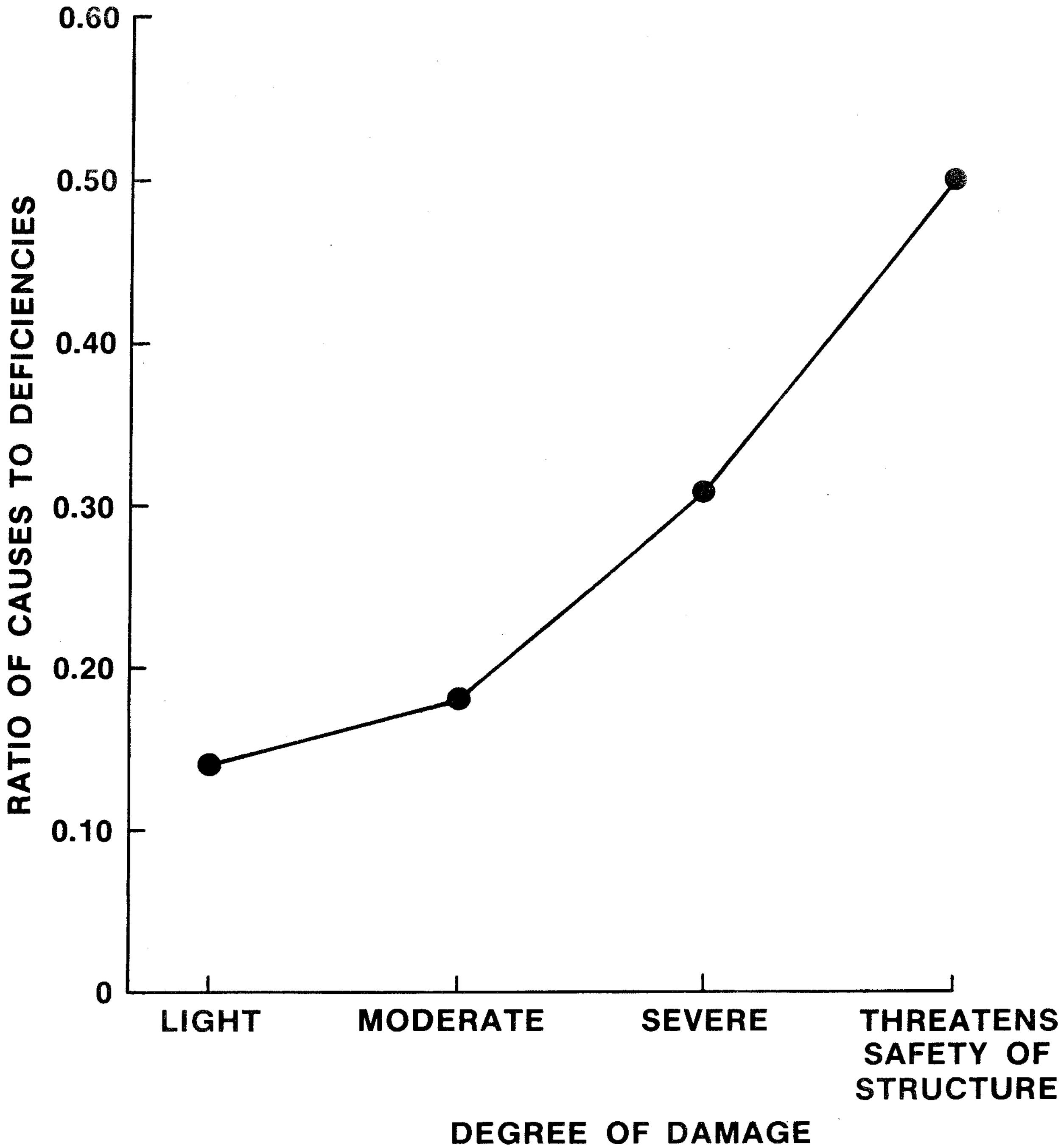


Figure 12. Relationship between ratio or reported causes to observed deficiencies and their degree of damage

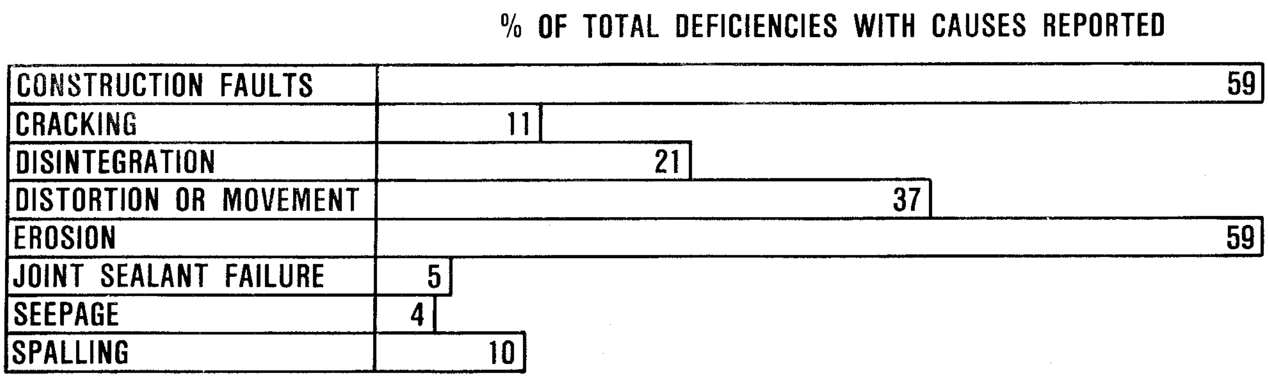


Figure 13. Percentage of total observed deficiencies for which causes were reported for eight categories of observed deficiencies

assigned to the deficiency at that location. There were slightly more locations (10,205) of deficiencies reported than deficiencies themselves (10,096). The major reason for this difference was a number of cases in which maintenance or repair activity was reported at a given location but no record could be found of the type of deficiency requiring this attention.

41. The most frequently reported locations of deficiencies were as follows:

Type of Structure	Location	No. of Deficiencies
Dam	Conduits	1147
Dam	Intake structures	719
Dam	Stilling basin walls	707
Dam	Monolith joints	659
Dam	Spillway faces	482
Dam	Piers	451
Lock	Chamber walls, vertical surfaces	416
Dam	Galleries	356
Lock	Chamber walls, horizontal surfaces	354
Lock	Monolith joints	283

These 10 locations accounted for 58 percent of the total locations where deficiencies were observed. The top 6 and 7 of the 8 most frequently reported locations of deficiencies were in dams.

42. Locations of observed deficiencies are summarized according to type of structure in Table 6. More than 60 percent of the total deficiencies reported were located in dams compared to 22 percent in navigation locks (Figure 14). One reason for the large number of problems with dams relative to locks is that the Corps owns and operates more than twice as many dams as lock chambers. The number of deficiencies located in each type of structure decreased with increasing degree of damage. This trend was particularly true for dams (Figure 15). In those cases in which degree of damage could be assigned to a deficiency at a given location, 96 percent of the deficiencies located in dams were classified as either light or moderate damage. This result indicates that most problems with dams will require maintenance activities along with continued surveillance and monitoring.

43. The number of navigation lock deficiencies, classified according to degree of damage, decreased with increasing severity of damage (Figure 15). However, as a percentage of the total deficiencies within a given degree of

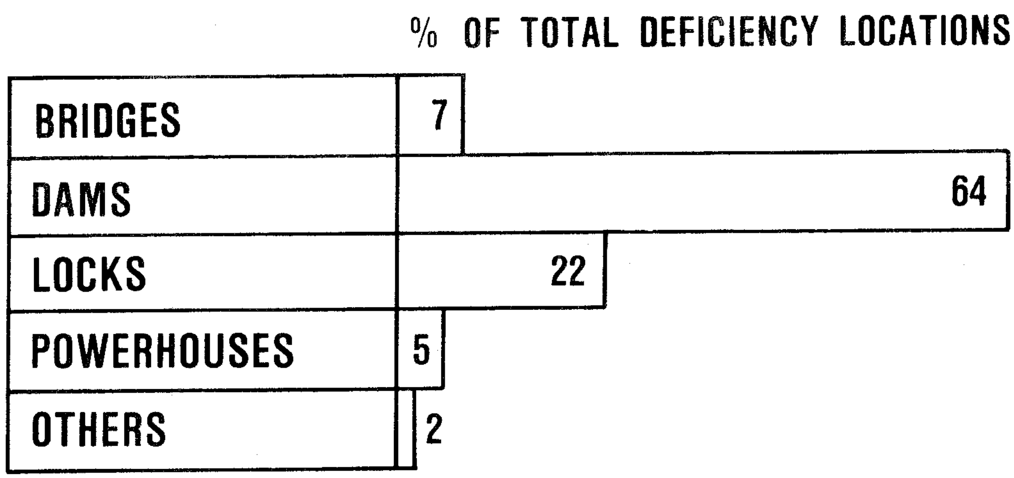


Figure 14. Percentage of total observed deficiency locations for five types of structures

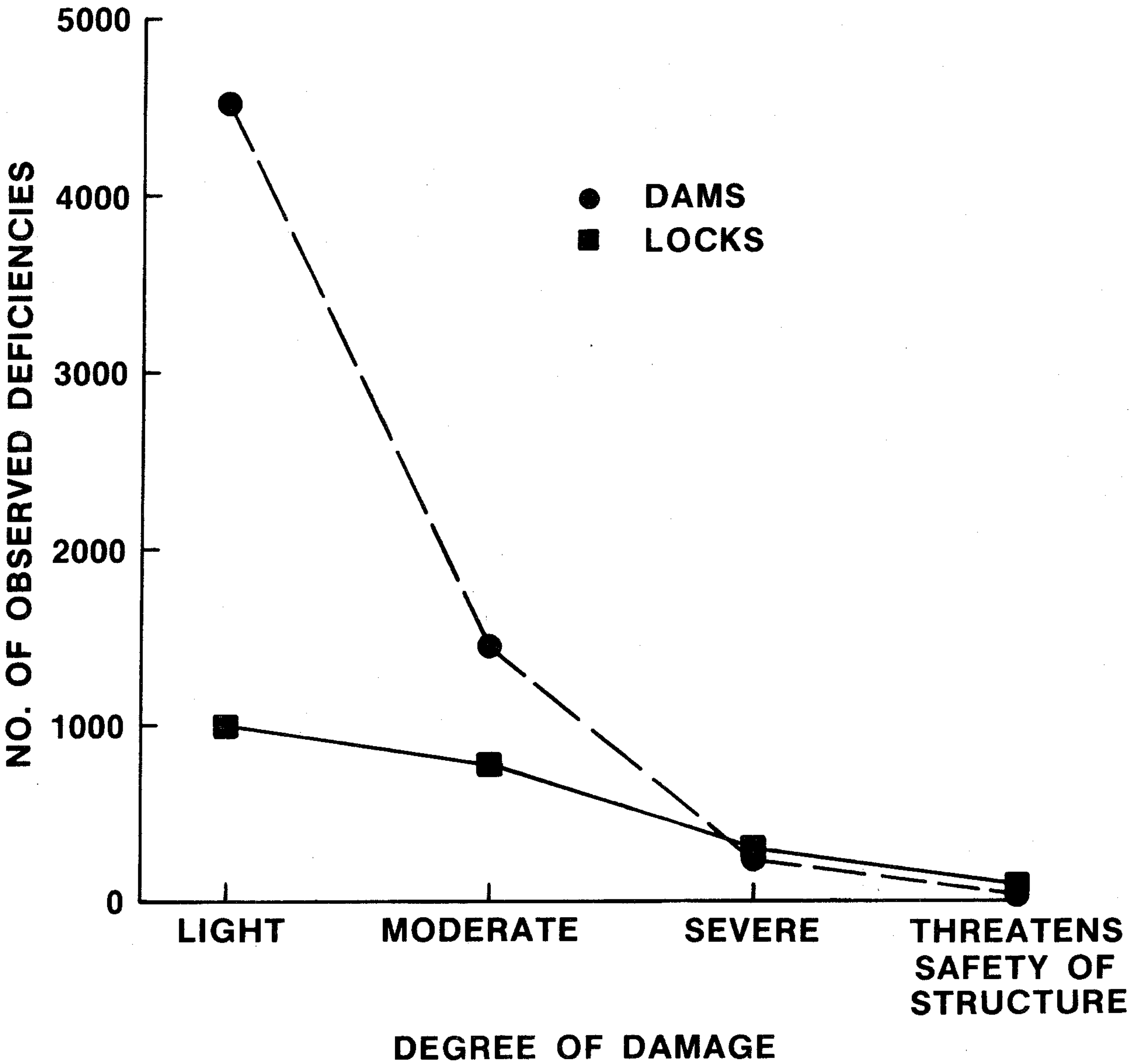


Figure 15. Relationship between number of deficiencies observed in locks and in dams and their degree of damage

damage classification, lock deficiencies increased with increased degree of damage (Figure 16). Also, the number of deficiencies located in locks was greater than that in dams for both the severe and threatens safety of structure classifications of damage. This result indicates that navigation locks will require emphasis on repair and rehabilitation in addition to normal maintenance activities.

44. Deficiencies observed in the various types of structures are shown in Tables 15-18 for individual damage classifications and summarized in Table 19. Concrete cracking was the most frequently observed deficiency in all types of structures. The data base can be searched to obtain additional information on the types of deficiencies observed at various locations within a type of structure. For example, the locations in dams of observed deficiencies classified as moderate damage are shown in Table 20. Similarly, information can be obtained on the types of deficiencies observed at a specific location such as dam conduits, the most frequently reported location of deficiencies (Table 21).

Degree of Damage

45. It was possible to classify observed deficiencies according to degree of damage in 96 percent of the total observations. The number of observed deficiencies (Figure 17) and the number of structures involved (Figure 18) decreased rapidly with increasing degree of damage. Deficiencies classified as light damage accounted for 67 percent of those classified according to degree of damage. Ninety-four percent of the observed deficiencies were classified as either light or moderate damage. There were 599 deficiencies, involving almost 200 structures, classified as either severe damage or threatens safety of structure. Deficiencies within these more serious damage classifications are expected to increase as the average age of Corps structures increases.

Repair Materials and Techniques

46. Repair and maintenance activities were described in the periodic inspection reports for less than 10 percent of the total observed deficiencies. As expected, the ratio of repaired deficiencies to total observed deficiencies within a damage classification increased with severity of damage (Figure 19). However, reports of repairs to only 20 and 33 percent of the deficiencies

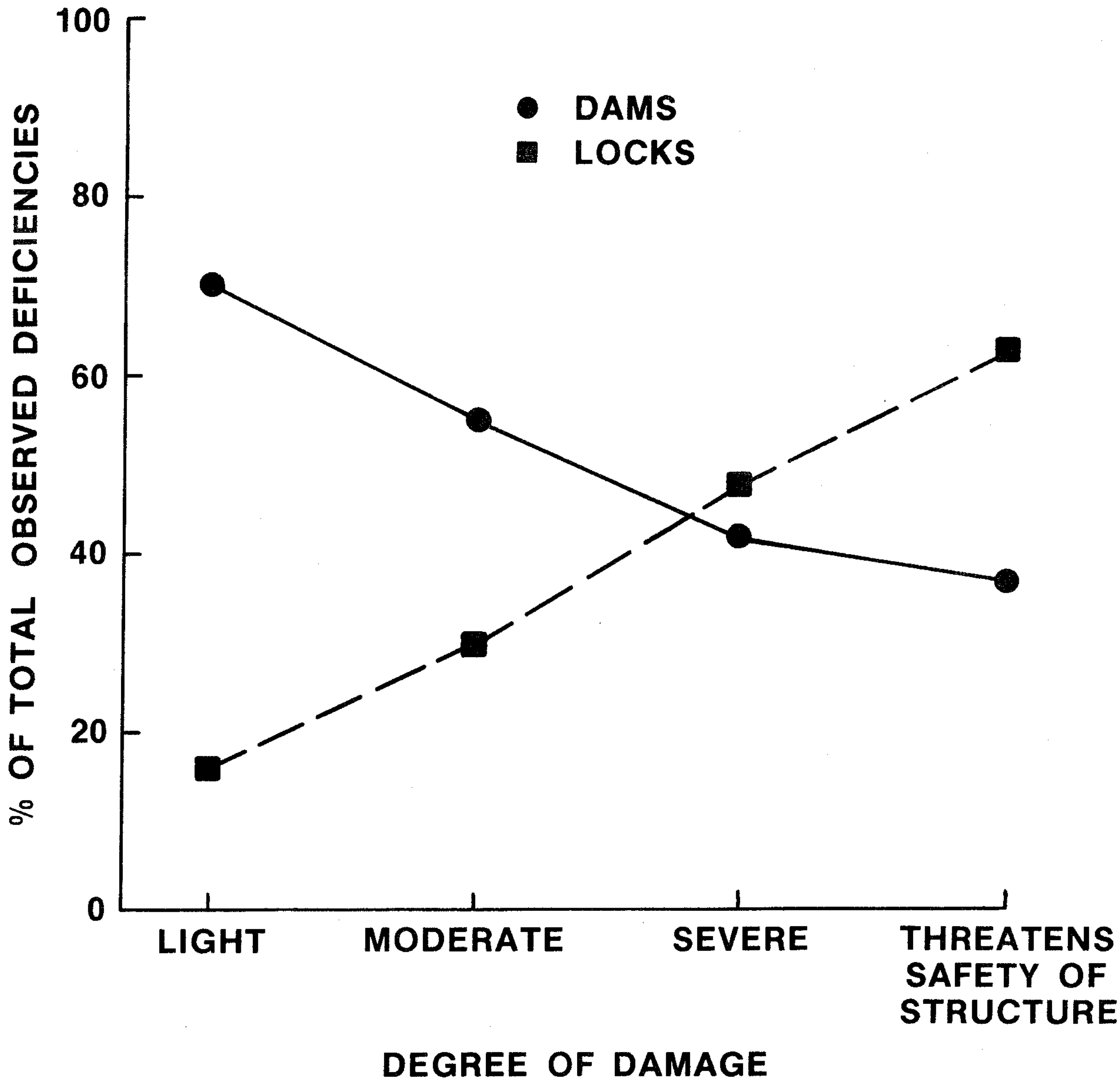


Figure 16. Relationship between percentage of total observed deficiencies in locks and in dams and their degree of damage

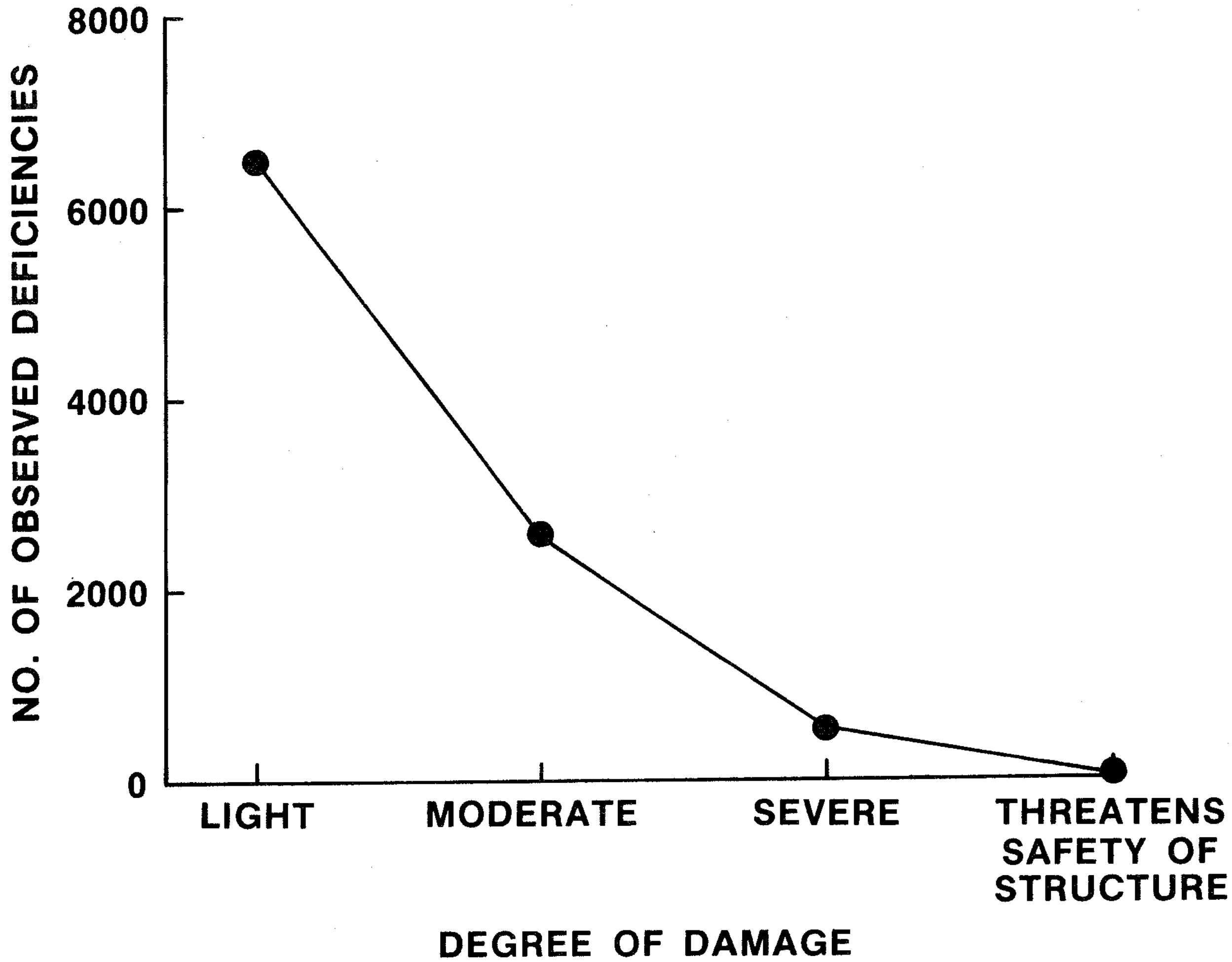


Figure 17. Relationship between number of observed deficiencies and their degree of damage

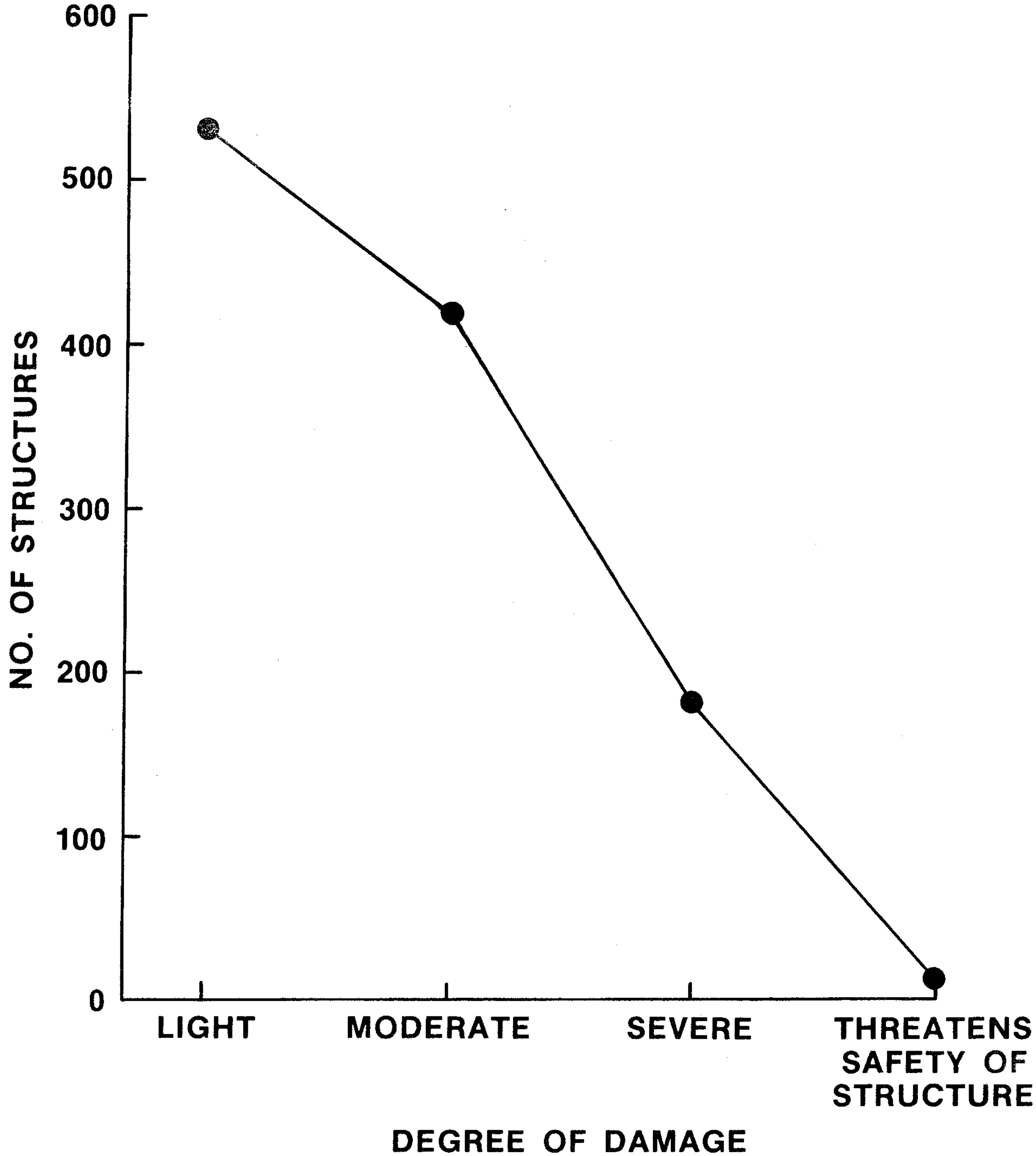


Figure 18. Relationship between number of structures with observed deficiencies and their degree of damage

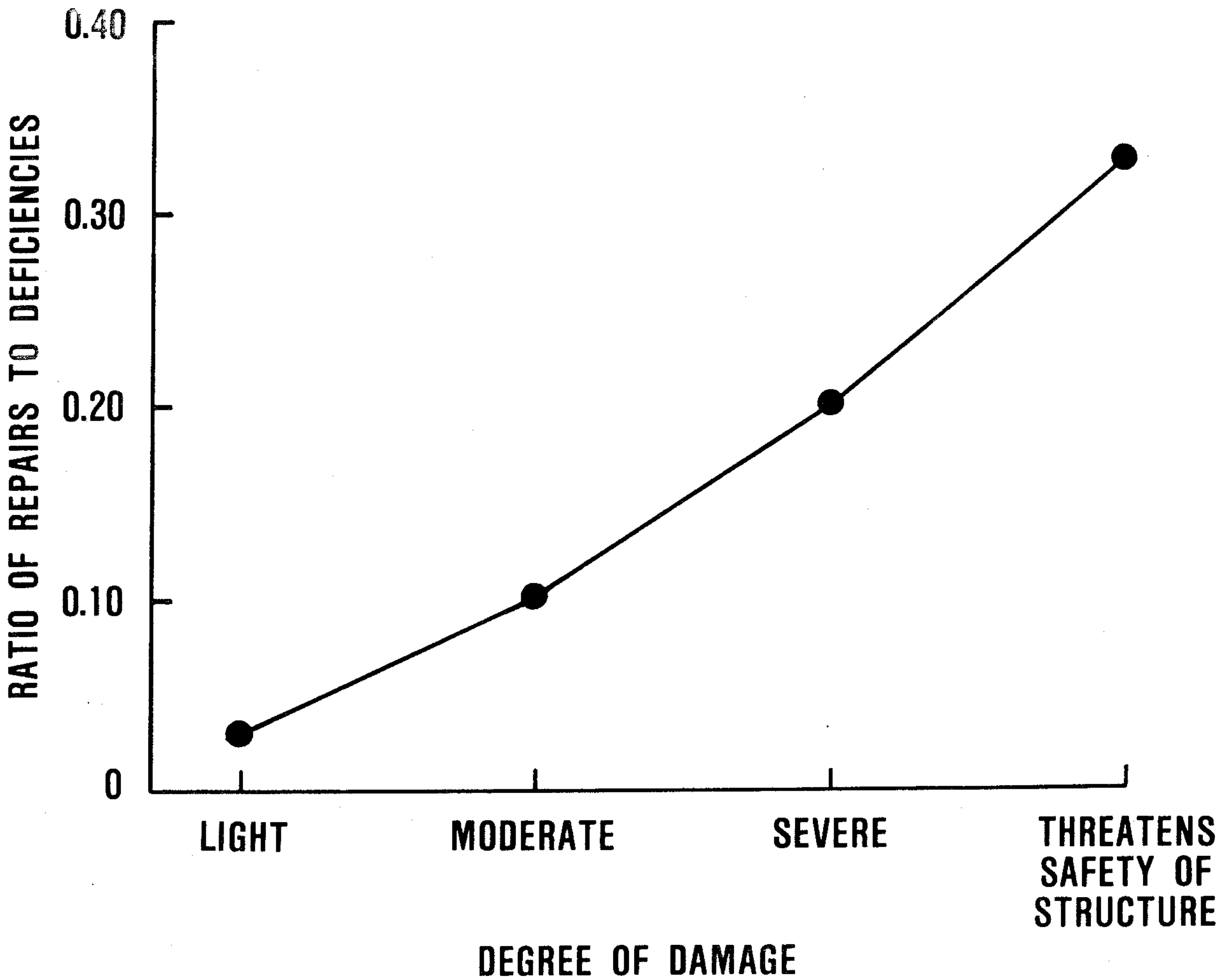


Figure 19. Relationship between ratio of number of repairs to number of observed deficiencies and their degree of damage

classified as severe damage and threatens safety of structure, respectively, were unexpectedly low. This result could be attributed in part to the time lag involved in observation and reporting of a deficiency in one inspection report and the repair being performed at some time prior to the following inspection (as much as 5 years later). More likely, this result could indicate a significant number of deficiencies awaiting attention. In either case, there is a need for increased attention in inspection reports to maintenance and repair activities, particularly regarding the types of materials used and their subsequent performance.

47. The types of observed deficiencies for which repairs have been reported are shown in Table 22. Cracking, spalling, and erosion were the types of deficiencies most often reported as having been repaired. These three types of deficiencies accounted for nearly 70 percent of the 569 cases in which a repair material could be related to a type of deficiency. There appears to be a general correlation between the number of deficiencies of a given type observed and the number repaired (Figure 20).

48. The locations of deficiencies which have been repaired are shown in Table 23. Fifty-four percent of the repairs reported were on dams, where 64 percent of the total deficiencies were observed (Table 6). In comparison, 33 percent of the repairs were on lock structures which accounted for 22 percent of the total observed deficiencies. This result is attributed to the fact that the numbers of deficiencies in locks were higher than those in dams for the more severe damage classifications (Figure 16).

49. The type of material used was reported for 699 maintenance and repair activities. The performance of the various materials could be rated in 618 cases as shown in Table 7 and summarized in Figure 21. Overall, the performance of the various materials was rated good for only half of the repairs, and for 35 percent of the cases the material performance was rated as either poor or failed. This result indicates a need for additional evaluation of existing materials prior to prototype application or development of improved materials for maintenance and repair or both.

50. There were four general types of materials (concrete, epoxy, grout, and joint sealants) which had more than 100 reported uses as repair materials. The relative performance of these materials is shown in Figure 22. The percentages of repair materials rated as good ranged from 39 to 66 percent for epoxy and joint sealants, respectively, with an average for the four materials of

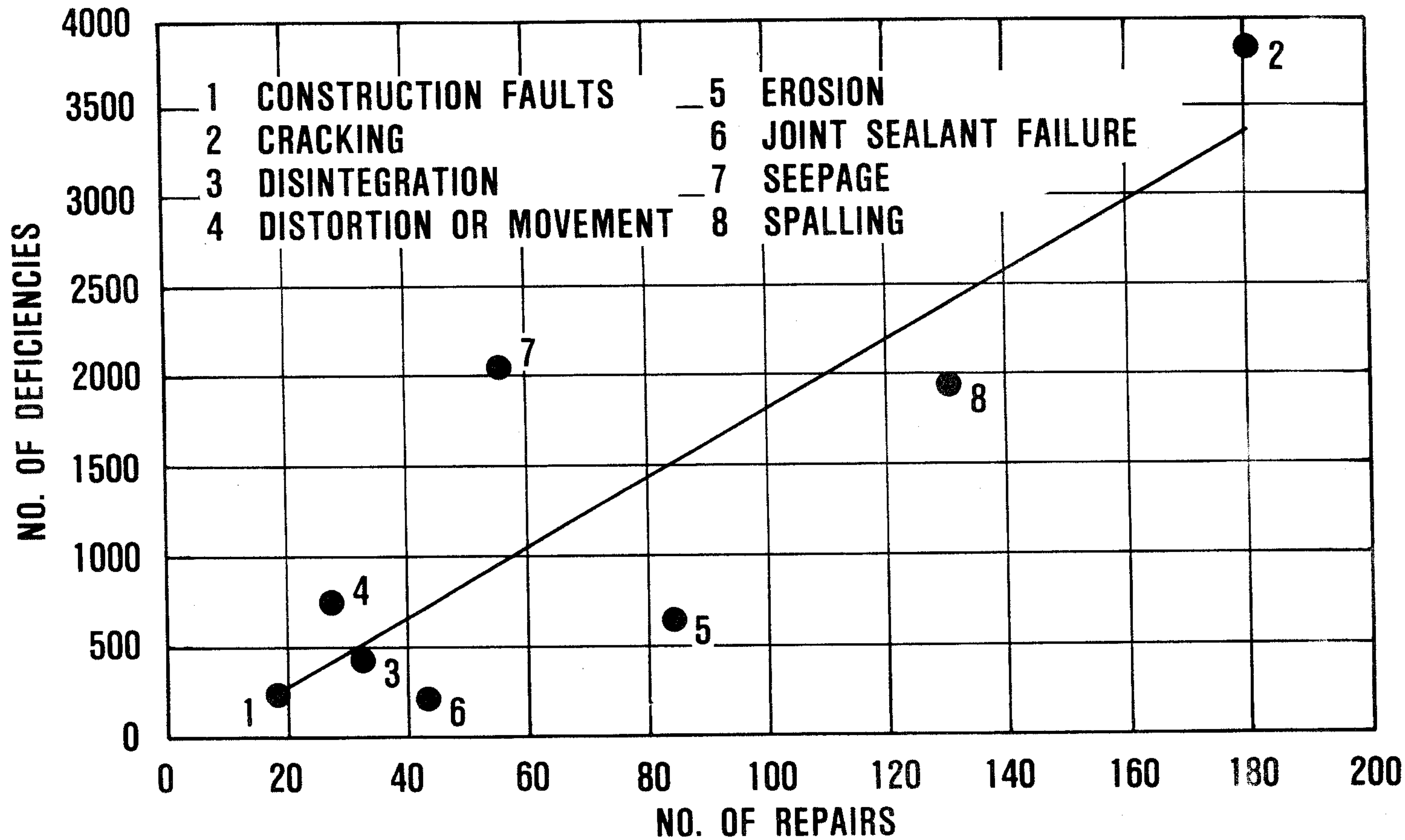


Figure 20. Relationship between number of observed deficiencies and number repaired for eight general categories of observed deficiencies

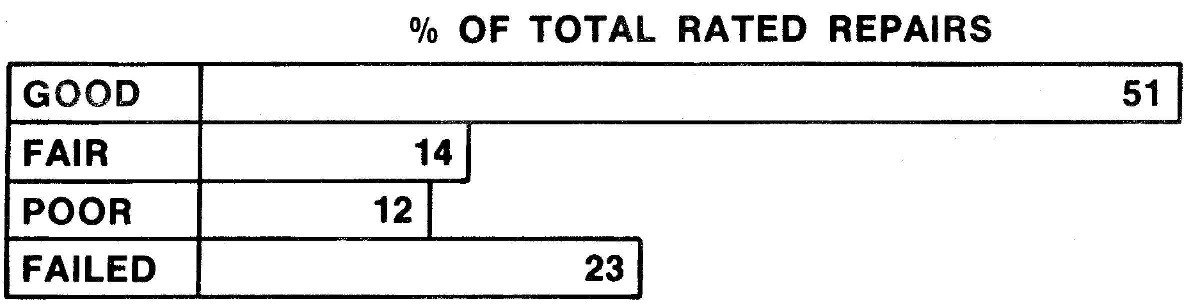


Figure 21. Performance of repair materials for which ratings were reported

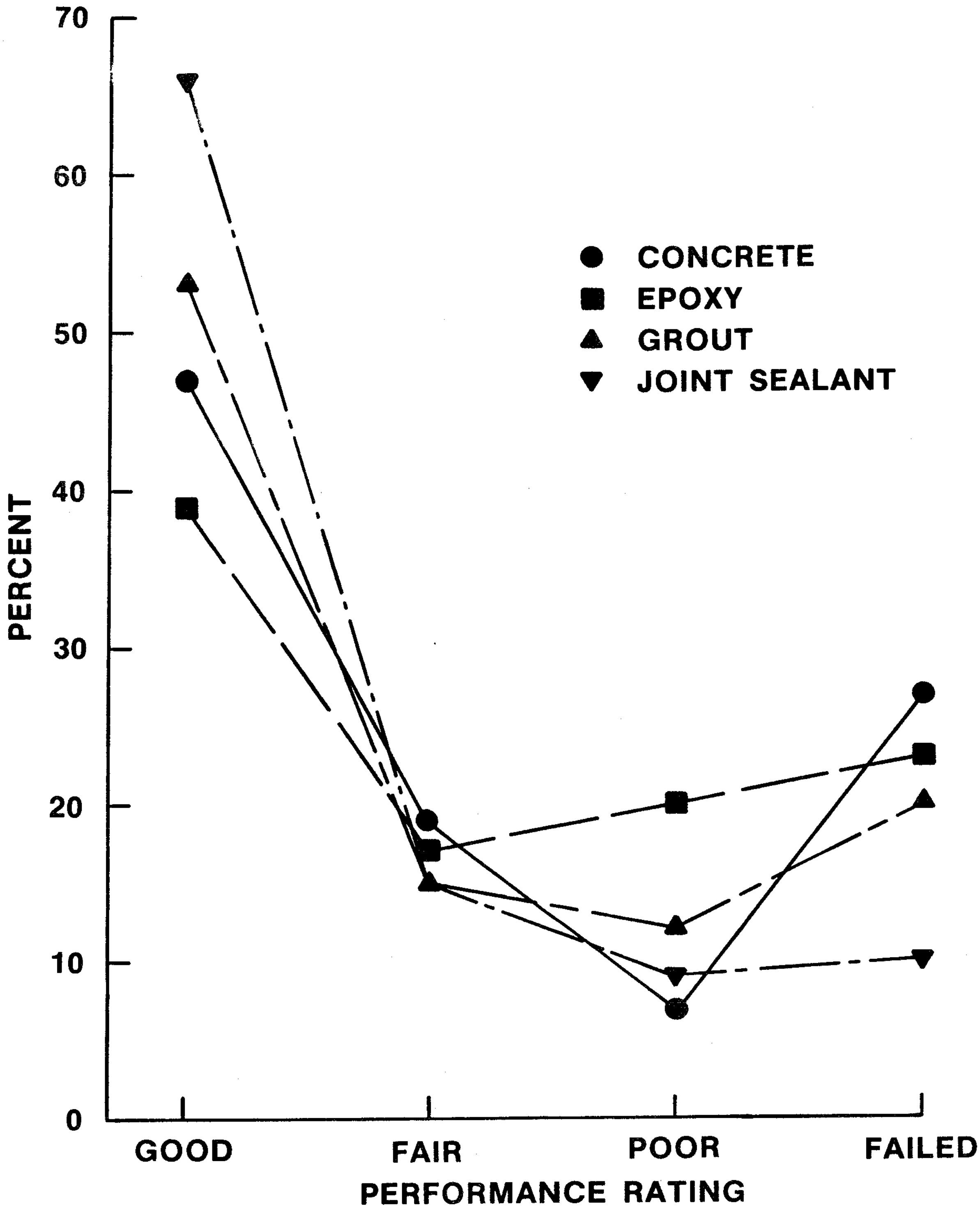


Figure 22. Relative performance of four general types of repair materials

51 percent. On the other end of the scale, joint sealants had the fewest reported failures (10 percent), whereas concrete had the most failures (27 percent).

51. The repair technique used was specified in 592 reports of maintenance and repair as compared to 699 reports on the type of material. The performance of the various techniques could be rated in 588 cases as shown in Table 8. As expected, performance ratings for the various repair techniques were essentially the same as ratings for the repair materials (Figure 23). Approximately half of the materials and techniques were rated good, a fourth failed, and the remaining fourth evenly divided between fair and poor.

52. Route and seal, conventional forming and placing, overlay, injection, and trowel-on were the techniques most frequently used. These five techniques accounted for 73 percent of the repairs reported. The percentages of repair techniques rated as good ranged from 40 to 57 percent for overlays and routing and sealing, respectively, with an average for the five techniques of 50 percent. With the performance of one out of every two repairs being rated as less than good, there is a need for significant improvements in selection and application of repair materials and techniques.

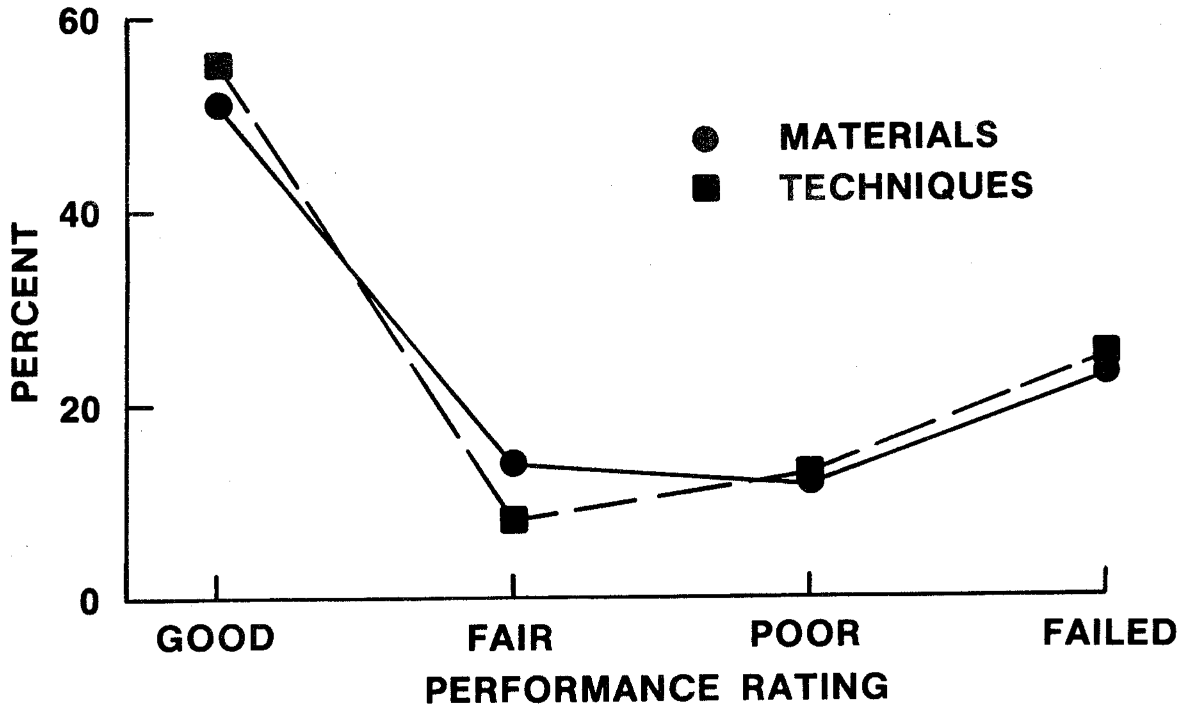


Figure 23. Relative performance of repair materials and techniques

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

53. Over 2000 periodic inspection reports were reviewed in an attempt to develop quantitative information on the condition of the concrete portions of the Corps' civil works structures. The information contained in the various reports varied widely both in content and detail. While the information is believed to be an adequate sample for the purposes of this report, uniform reporting procedures Corps-wide would improve the potential of these reports in identifying future trends and problem areas in maintenance and repair of civil works structures.

54. There was no apparent correlation between the average age of structures within a given Division and the overall number of deficiencies observed. However, considering only those deficiencies classified as severe damage or threatens safety of structure, there was a general correlation between the average age of structures and the number of deficiencies. This would indicate that, as Corps structures remain in service and their average age increases, the number of deficiencies requiring repair will increase.

55. Concrete cracking was the deficiency most often observed (3842 observations) accounting for 38 percent of the total deficiencies. Other major problem areas, based on the number of deficiencies, were seepage and spalling, which accounted for 20 and 19 percent of the total, respectively. Development of equipment, materials, and techniques to evaluate and correct these types of deficiencies should be emphasized in the REMR Research Program.

56. Overall, causes of observed deficiencies were reported for only 17 percent of the total deficiencies. As might be expected, the more severe the damage, the more cases in which the cause of the deficiency was reported. However, even in those instances in which the severity of damage was such that repairs were required, causes were reported for only 31 and 50 percent of the deficiencies classified as severe and threatens safety of structure, respectively. This result indicates a need for improved evaluation equipment and procedures. Also, additional training of inspection personnel in visual evaluation and classification of concrete condition and increased attention to detail in reporting procedures appear warranted.

57. More than 60 percent of the total deficiencies reported were located in dams compared to 22 percent in navigation locks. One reason for the large number of problems with dams relative to locks is that the Corps owns and operates more than twice as many dams as lock chambers. The number of deficiencies located in each type of structure decreased with increasing degree of damage. In those cases in which degree of damage could be assigned to a deficiency at a given location, 96 percent of the deficiencies located in dams were classified as either light or moderate damage. This result indicates that the majority of problems with dams will require maintenance activities along with continued surveillance and monitoring.

58. Although the overall number of concrete deficiencies located in navigation locks was approximately one-third the number in dams, the number of deficiencies in locks was greater than that in dams for both the severe and threatens safety of structure classifications of damage. This result indicates that navigation locks will require emphasis on repair and rehabilitation in addition to normal maintenance activities.

59. Most of the observed deficiencies (94 percent) were classified as light or moderate damage indicating a need for emphasis on maintenance activities. However, there were 599 reported deficiencies, involving almost 200 structures, classified as either severe damage or threatens safety of structure. Deficiencies within these more serious damage classifications are expected to increase as the average age of Corps structures increases.

60. Repair and maintenance activities were described in the periodic inspection reports for less than 10 percent of the total deficiencies observed. As expected, the ratio of repaired deficiencies to total observed deficiencies within a given damage classification increased with severity of damage. However, reports of repairs to only 20 and 33 percent of the deficiencies classified as severe damage and threatens safety of structure, respectively, were unexpectedly low. This result could be attributed in part to the time lag involved in observation and reporting of a deficiency in one inspection report and the repair being performed at some time prior to the following inspection (as much as 5 years later). More likely, this indicates a significant backlog of concrete deficiencies awaiting attention. In either case, there is a need for increased attention in inspection reports to maintenance and repair activities, particularly regarding the types of materials used and their subsequent performance.

61. Overall, the performance of the various maintenance and repair materials was rated good for only half of the repairs, and for 35 percent of the cases the material performance was rated as either poor or failed. With the performance of one out of every two repairs being rated as less than good, there is a need for significant improvements in selection and application of repair materials and techniques.

Recommendations

62. Information contained in the present data bases on the condition of concrete in the Corps' civil works structures should be a valuable asset to both field and laboratory personnel involved in maintenance and repair activities. Consequently, additional efforts to locate missing inspection reports to complete the data bases are recommended. Also, to keep the data bases current, future inspection reports should be reviewed and input into the data bases as they become available.

63. An easy, timesaving system of visual methods for uniform identification and classification of concrete deterioration symptoms should be developed for future inspection reports. Such a system should be based on detailed definitions of typical concrete damage adequately illustrated with photographic examples similar to an expanded version of those shown in Appendix C. Data sheets or hand-held field data entry devices or both should be developed to ease data collection and transmission.

64. This identification and assessment of problems relating to evaluation, maintenance, and repair of concrete should be used in developing and establishing research priorities in the REMR Research Program. In addition, principal investigators for research work units in the REMR Concrete and Steel Structures problem area should use the existing data bases to develop background information on the specific problems being addressed in the individual work units.

Table 1

Observed Deficiencies

Code	Type	Overall	No. Unclassified	Light	Moderate	Severe	Threatens Safety of Structure
	Deficiency			No. of Deficiencies Classified by Degree of Damage			
110	Construction faults (unspecified)	28	8	14	2	4	0
111	Bug holes	24	2	20	1	1	0
112	Cold joints	23	1	19	3	0	0
113	Exposed reinforcing steel	27	1	20	2	3	1
114	Honeycombing	36	4	24	5	3	0
115	Irregular surface	91	2	75	12	2	0
	Total	229	18	172	25	13	1
120	Cracking (unspecified)	1,725	83	1142	420	77	3
121	Checking or crazing	51	3	39	8	1	0
122	D-cracking	7	0	6	1	0	0
123	Diagonal	130	1	74	47	8	0
124	Hairline	314	3	275	36	0	0
125	Longitudinal	340	9	169	143	14	5
126	Map or pattern	110	8	77	24	1	0
127	Random	167	2	103	54	6	2
128	Transverse	372	8	212	142	9	1
129	Vertical	431	3	261	150	17	0
130	Horizontal	195	3	115	69	8	0
	Total	3,842	123	2473	1094	141	11

(Continued)

Table 1 (Continued)

Deficiency				No. of Deficiencies Classified by Degree of Damage			
Code	Type	Overall	No. Unclassified	Light	Moderate	Severe	Threatens Safety of Structure
140	Disintegration (unspecified)	169	12	50	63	43	1
141	Blistering	1	0	0	1	0	0
143	Delamination	3	0	1	2	0	0
144	Drummy area	16	1	9	6	0	0
145	Dusting	3	0	2	1	0	0
146	Peeling	6	2	3	1	0	0
147	Scaling	96	3	37	37	19	0
148	Weathering	141	4	64	43	27	3
	Total	435	22	166	154	89	4
155	Distortion or movement (unspecified)	416	30	258	86	38	4
156	Buckling	3	0	2	0	1	0
157	Curling	2	0	1	0	1	0
159	Settling	229	7	150	58	14	0
160	Tilting	95	5	52	22	11	5
161	Warping	2	0	2	0	0	0
	Total	747	42	465	166	65	9
170	Erosion (unspecified)	475	35	261	125	54	0
171	Abrasion	90	7	48	32	3	0
172	Cavitation	77	19	27	21	10	0
	Total	642	61	336	178	67	0
175	Joint sealant failure — Total	217	14	61	100	42	0

(Continued)

Table 1 (Concluded)

Deficiency				No. of Deficiencies Classified by Degree of Damage			
Code	Type	Overall	No. Unclassified	Light	Moderate	Severe	Threatens Safety of Structure
180	Seepage (unspecified)	1,322	38	970	270	42	2
181	Corrosion	37	1	26	6	4	0
182	Discoloration or staining	127	0	109	14	0	0
183	Exudation	6	0	4	2	0	0
184	Efflorescence	546	2	447	94	3	0
185	Incrustation	10	2	7	1	0	0
	Total	2,048	43	1563	387	53	2
190	Spalling (unspecified)	1,791	68	1133	489	98	3
191	Pitting	44	0	40	4	0	0
192	Popouts	101	0	85	15	1	0
	Total	1,936	68	1258	508	99	3
	Overall Total	10,096	391	6494	2612	569	30

Table 2

Summary of Observed Deficiencies

Deficiency			Deficiencies Classified by Degree of Damage											
			Light			Moderate			Severe			Threatens Safety of Structure		
Type	No.	% of Total	No.	% of Total	No. of Structures	No.	% of Total	No. of Structures	No.	% of Total	No. of Structures	No.	% of Total	No. of Structures
Construction faults	229	2	172	3	112	25	1	18	13	2	9	1	3	1
Cracking	3,842	38	2473	38	494	1094	42	320	141	25	75	11	37	6
Disintegration	435	4	166	3	101	154	6	82	89	16	41	4	13	2
Distortion or movement	747	7	465	7	255	166	6	101	65	11	38	9	30	4
Erosion	642	6	336	5	200	178	7	85	67	12	34	0	0	0
Joint sealant failure	217	2	61	1	44	100	4	65	42	7	28	0	0	0
Seepage	2,048	20	1563	24	420	387	15	189	53	9	33	2	7	2
Spalling	1,936	19	1258	19	417	508	19	234	99	17	63	3	10	2
Total	10,096		6494			2612			569			30		

Table 3

Causes of Observed Deficiencies

Cause				No. of Deficiencies Classified by Degree of Damage			
Code	Type	Overall	No. Unclassified	Light	Moderate	Severe	Threatens Safety of Structure
210	Accidental loading (unspecified)	8	0	1	5	2	0
211	Earthquake	11	0	3	2	4	2
212	Impact	117	4	49	39	24	1
213	Overloading	3	0	2	0	0	1
	Total	139	4	55	46	30	4
220	Chemical reactions (unspecified)	24	0	17	7	0	0
221	Acid water	8	0	2	4	2	0
222	Aggressive water	1	0	0	1	0	0
223	Alkali-carbonate rock reaction	0	0	0	0	0	0
224	Alkali-silica reaction	17	0	5	6	4	2
225	Chemical attack (type unknown)	9	0	1	7	1	0
226	Sulfate attack	5	2	1	2	0	0
	Total	64	2	26	27	7	2
230	Construction faults Total	243	30	149	53	10	1
235	Maintenance faults Total	14	0	12	2	0	0
240	Corrosion Total	41	0	27	10	4	0
250	Design errors (unspecified)	32	2	11	7	9	3
251	Faulty design details	8	0	5	0	3	0
252	Under-designed	12	1	5	2	4	0
	Total	52	3	21	9	16	3

(Continued)

Table 3 (Concluded)

Cause					No. of Deficiencies Classified by Degree of Damage			
Code	Type		Overall	No. Unclassified	Light	Moderate	Severe	Threatens Safety of Structure
260	Erosion (unspecified)		160	24	71	40	25	0
261	Abrasion		146	6	71	58	11	0
262	Cavitation		108	21	50	25	12	0
		Total	414	51	192	123	48	0
270	Settlement or movement	Total	314	25	168	93	23	5
275	Shrinkage (unspecified)		247	2	205	40	0	0
276	Drying		2	0	0	2	0	0
		Total	249	2	205	42	0	0
280	Temperature (unspecified)		46	2	36	8	0	0
282	Fire		4	1	3	0	0	0
283	Internally generated		5	0	3	2	0	0
		Total	55	3	42	10	0	0
290	Weathering (unspecified)		30	2	9	13	6	0
291	Freezing and thawing		84	2	16	34	32	0
		Total	114	4	25	47	38	0
		Overall Total	1699	124	922	462	176	15

(Sheet 2 of 2)

Table 4

Summary of Causes of Observed Deficiencies

Type	No.	% of Total	Light No.	Light % of Total	Moderate No.	Moderate % of Total	Severe No.	Severe % of Total	Threatens Safety of Structure No.	Threatens Safety of Structure % of Total
Accidental loading	139	8	55	6	46	10	30	17	4	27
Chemical reactions	64	4	26	3	27	6	7	4	2	13
Construction faults	243	14	149	16	53	11	10	6	1	7
Maintenance faults	14	1	12	1	2	0	0	0	0	0
Corrosion	41	2	27	3	10	2	4	2	0	0
Design errors	52	3	21	2	9	2	16	9	3	20
Erosion	414	24	192	21	123	27	48	27	0	0
Settlement or movement	314	18	168	18	93	20	23	13	5	33
Shrinkage	249	15	205	22	42	9	0	0	0	0
Temperature	55	3	42	5	10	2	0	0	0	0
Weathering	114	7	25	3	47	10	38	22	0	0
Total	1699		922		462		176		15	

Causes Classified by Degree of Damage: Light, Moderate, Severe, Threatens Safety of Structure.

Table 5

Locations of Observed Deficiencies

Location				No. of Locations Classified by Degree of Damage			
Code	Type	Overall	No. Unclassified	Light	Moderate	Severe	Threatens Safety of Structure
310	Bridges (unspecified)	26	3	17	6	6	0
311	Decks	228	6	162	55	5	0
312	Expansion joints	63	12	30	16	5	0
313	Piers, pedestals, or abutments	230	7	159	52	12	0
314	Parapet walls	60	2	39	16	3	0
315	Bearings	76	7	33	26	10	0
	Total	683	37	440	171	35	0

(Continued)

Table 5 (Continued)

Location				No. of Locations Classified by Degree of Damage			
Code	Type	Overall	No. Unclassified	Light	Moderate	Severe	Threatens Safety of Structure
320	Dams (unspecified)	88	15	46	26	1	0
321	Conduits	1,147	69	793	261	24	0
322	Downstream face	128	1	97	28	2	0
323	Drains	17	0	9	8	0	0
324	Flip buckets	27	2	23	1	1	0
325	Galleries	356	4	263	86	3	0
326	Gates	237	5	161	46	24	1
327	Gate anchorages	65	4	36	21	4	0
328	Horizontal construction joints	160	2	118	39	1	0
329	Intake structures	719	17	599	89	14	0
330	Monolith joints	659	35	458	137	29	0
331	Piers or abutments	451	20	272	134	21	4
332	Sluices	128	4	102	16	6	0
333	Spillway crest (ogee)	276	16	191	63	6	0
334	Spillway face	482	21	323	126	12	0
335	Stilling basin, baffles	90	4	55	24	7	0
336	Stilling basin, floor	249	16	130	79	24	0
337	Stilling basin walls	707	29	512	129	34	3
338	Upstream face	76	7	37	27	3	2
339	Spillway monolith	128	3	93	28	4	0
340	Slope paving	34	2	18	4	10	0
341	Outlet works (separate from spillway)	53	5	38	7	3	0
342	Approach	47	3	24	16	3	1
343	End sill	79	6	60	12	1	0
344	Horizontal (top face)	115	6	70	39	0	0
	Total	6,518	296	4528	1446	237	11

(Continued)

Table 5 (Continued)

Location				No. of Locations Classified by Degree of Damage			
Code	Type	Overall	No. Unclassified	Light	Moderate	Severe	Threatens Safety of Structure
345	Locks (unspecified)	66	8	32	20	6	0
346	Chamber walls, vertical surfaces	416	26	161	166	61	2
347	Chamber walls, horizontal surfaces	354	17	134	165	37	1
348	Emptying and filling conduits	124	11	59	49	5	0
349	Floor	42	3	15	16	4	4
350	Galleries	266	6	170	77	12	1
351	Gates	93	4	55	17	13	4
352	Guard walls	100	6	51	31	11	1
353	Guide walls	243	10	111	80	42	0
354	Horizontal construction joints	37	2	16	16	2	1
355	Monolith joints	283	18	123	98	44	0
356	Sill blocks	43	2	25	14	2	0
357	Lock monoliths	160	17	59	44	35	5
	Total	2,227	130	1011	793	274	19

(Continued)

Table 5 (Concluded)

Location				No. of Locations Classified by Degree of Damage			
Code	Type	Overall	No. Unclassified	Light	Moderate	Severe	Threatens Safety of Structure
365	Powerhouses (unspecified)	60	6	46	8	0	0
366	Bridge crane	7	0	4	3	0	0
367	Draft tubes	30	1	24	4	1	0
368	Exterior walls	35	0	24	10	1	0
369	Floors	44	4	29	11	0	0
370	Horizontal construction joints	23	2	17	3	1	0
371	Intake structure	21	5	11	5	0	0
372	Interior walls	86	4	65	17	0	0
373	Roof	30	4	15	11	0	0
374	Tailrace deck	11	0	8	2	1	0
375	Vertical construction joints	48	3	35	10	0	0
376	Walls	45	3	25	16	1	0
377	Penstock	56	0	40	15	1	0
378	Galleries	57	0	42	15	0	0
	Total	553	32	385	130	6	0
390	Other (unspecified)	51	1	28	17	5	0
391	Esplanade	74	2	40	27	5	0
392	Fish facilities	19	1	10	5	3	0
393	Floodwalls	8	0	8	0	0	0
394	Retaining walls	70	3	40	23	4	0
395	Dikes	2	0	1	0	1	0
	Total	224	7	127	72	18	0
	Overall Total	10,205	502	6491	2612	570	30

(Sheet 4 of 4)

Table 6

Summary of Locations of Observed Deficiencies

Location			Locations Classified by Degree of Damage							
			Light		Moderate		Severe		Threatens Safety of Structure	
Type	No.	% of Total	No.	% of Total	No.	% of Total	No.	% of Total	No.	% of Total
Bridges	683	7	440	7	171	7	35	6	0	0
Dams	6,518	64	4528	70	1446	55	237	42	11	37
Locks	2,227	22	1011	16	793	30	274	48	19	63
Powerhouses	553	5	385	6	130	5	6	1	0	0
Other	224	2	127	2	72	3	18	3	0	0
Total	10,205		6491		2612		570		30	

Table 7

Repair Materials

Code	Type		No. of Uses: Overall	No. of Uses: Unclassified	No. of Repairs Classified by Performance of Repair Material: Good	Fair	Poor	Failed
500	Unspecified	Total	204	65	81	9	15	34
510	Concrete (unspecified)		109	24	36	18	6	25
511	Conventional (portland cement)		25	17	5	0	0	3
513	Fiber reinforced (steel)		8	2	5	0	1	0
516	Polymer-impregnated (PIC)		4	1	2	1	0	0
		Total	144	44	48	19	7	28
520	Epoxy	Total	115	21	37	16	19	22
525	Grout (unspecified)		66	17	22	5	8	14
526	Chemical		9	3	3	2	1	0
527	Portland cement		13	6	6	1	0	0
528	Epoxy		19	6	9	3	0	1
		Total	107	32	40	11	9	15
530	Joint sealants (unspecified)		83	25	39	8	4	7
531	Field-molded mastic		8	8	0	0	0	0
532	Field-molded thermoplastic (hot applied)		1	0	1	0	0	0
533	Field-molded thermoplastic (cold applied)		3	1	0	0	2	0
534	Field-molded thermosetting (chemical curing)		3	1	2	0	0	0
536	Preformed compression seal		6	2	2	2	0	0
		Total	104	37	44	10	6	7

(Continued)

Table 7 (Continued)

Material								
		No. of Uses		No. of Repairs Classified by Performance of Repair Material				
Code	Type	Overall	Unclassified	Good	Fair	Poor	Failed	
540	Mortar (unspecified)	17	7	7	0	1	2
541	Epoxy	38	15	7	5	6	5
542	Portland cement	7	4	2	0	0	1
	Total	62	26	16	5	7	8
545	Paint Total	2	1	0	1	0	0
550	Shotcrete (unspecified) Total	38	4	9	3	7	15
560	Steel	8	1	6	0	1	0
563	Plate	13	5	2	2	0	4
564	Posttensioning strand or bars	15	8	7	0	0	0
565	Rock anchors	3	2	1	0	0	0
566	Magnesium oxide anodes	6	3	1	2	0	0
	Total	45	19	17	4	1	4
570	Surface sealants or coatings (unspecified)	48	22	12	4	2	8
571	Acrylics	2	1	0	0	0	1
572	Bituminous	8	2	5	0	1	0
574	Neoprene	5	2	0	1	0	2
575	Urethane	2	0	1	1	0	0
	Total	65	27	18	6	3	11

(Continued)

Table 7 (Concluded)

Material				No. of Repairs Classified by Performance of Repair Material			
		No. of Uses					
Code	Type	Overall	Unclassified	Good	Fair	Poor	Failed
580	Waterstops (unspecified)	5	2	3	0	0	0
581	Metal	1	1	0	0	0	0
583	Rubber	4	2	1	0	0	1
	Total	10	5	4	0	0	1
590	Asphalt Total	5	4	0	1	0	0
	Overall Total	903	285	314	85	74	145

(Sheet 3 of 3)

Table 8

Repair Techniques

Technique		No. of Uses		No. of Repairs Classified by Performance of Repair Material			
Code	Type	Overall	Unclassified	Good	Fair	Poor	Failed
600	Unspecified	329	100	127	27	27	48
603	Brush-on	41	11	11	5	1	13
604	Cathodic protection	6	3	1	2	0	0
606	Conventional forming and placing	100	31	35	1	10	23
609	Drilling and plugging	21	6	13	1	0	1
612	Dry pack	6	1	3	2	0	0
615	Injection	71	27	23	7	5	9
618	Jacketing	1	1	0	0	0	0
624	Overlay	97	22	30	17	11	17
627	Polymer impregnation	3	1	1	1	0	0
630	Posttensioning	18	10	8	0	0	0
633	Precast elements	4	1	1	0	2	0
636	Preplaced aggregate	1	1	0	0	0	0
639	Roll-on	1	0	0	0	0	1
642	Route and seal	102	41	35	12	4	10
645	Shotcrete (dry-mix)	1	0	0	0	0	1
648	Shotcrete (wet-mix)	20	1	1	1	6	11
654	Spray-on	7	3	1	1	1	1
657	Stitching	1	0	1	0	0	0
658	Sawing for stress relief	20	9	10	0	0	1

(Continued)

Table 8 (Concluded)

Technique		No. of Uses		No. of Repairs Classified by Performance of Repair Material			
Code	Type	Overall	Unclassified	Good	Fair	Poor	Failed
660	Trowel-on	63	19	21	8	5	10
663	Underwater placement (preplaced aggregate)	4	2	0	0	2	0
666	Underwater placement (pump)	1	0	1	0	0	0
669	Underwater placement (tremie)	3	3	0	0	0	0
	Total	921	293	323	85	74	146

(Sheet 2 of 2)

Table 9

Observed Deficiencies by Corps Division

Code	Deficiency Type	No.	No. of Deficiencies Classified by Corps Division									
			LMVD	MRD	NAD	NCD	NED	NPD	ORD	SAD	SPD	SWD
110	Construction faults (unspecified)	28	7	8	0	0	1	3	3	3	0	3
111	Bug holes	24	7	5	0	0	0	4	3	0	2	3
112	Cold joints	23	0	1	0	2	0	1	5	0	2	12
113	Exposed reinforcing steel	27	8	2	2	3	2	0	2	1	0	7
114	Honeycombing	36	6	3	1	4	9	1	6	0	0	6
115	Irregular surfaces	91	4	12	5	5	3	11	11	9	4	27
	Total	229	32	31	8	14	15	20	30	13	8	58
120	Cracking (unspecified)	1,725	135	129	73	240	78	193	390	171	84	232
121	Checking or crazing	51	0	0	1	1	3	5	16	16	1	8
122	D-cracking	7	0	7	0	0	0	0	0	0	0	0
123	Diagonal	130	8	12	4	12	12	17	21	11	12	21
124	Hairline	314	26	26	28	18	26	29	39	6	39	77
125	Longitudinal	340	23	38	18	22	11	41	93	17	17	60
126	Map or pattern	110	5	51	1	13	12	10	2	3	8	5
127	Random	167	12	6	1	3	5	13	86	12	14	15
128	Transverse	372	25	35	10	13	17	49	83	28	23	89
129	Vertical	431	43	55	9	37	55	54	69	37	13	59
130	Horizontal	195	9	18	2	18	25	22	38	23	3	37
	Total	3,842	286	377	147	377	244	433	837	324	214	603

(Continued)

Table 9 (Continued)

Code	Deficiency Type	No.	LMVD	MRD	NAD	NCD	NED	NPD	ORD	SAD	SPD	SWD
			No. of Deficiencies Classified by Corps Division									
140	Disintegration (unspecified)	169	5	12	2	2	0	4	123	4	1	16
141	Blistering	1	0	0	0	0	1	0	0	0	0	0
143	Delamination	3	2	1	0	0	0	0	0	0	0	0
144	Drummy area	16	0	8	1	1	0	1	2	0	1	2
145	Dusting	3	1	0	0	0	0	1	0	1	0	0
146	Peeling	6	0	1	0	0	2	0	1	0	1	1
147	Scaling	96	3	8	6	41	6	10	12	2	0	8
148	Weathering	141	1	4	5	13	3	5	100	7	2	1
	Total	435	12	34	14	57	12	21	238	14	5	28
155	Distortion or movement (unspecified)	416	72	36	17	52	10	23	78	23	30	75
156	Buckling	3	0	2	1	0	0	0	0	0	0	0
157	Curling	2	0	0	0	2	0	0	0	0	0	0
159	Settling	229	39	44	11	19	1	9	36	18	22	30
160	Tilting	95	13	23	6	16	3	3	2	7	7	15
161	Warping	2	0	1	0	0	0	0	0	1	0	0
	Total	747	124	106	35	89	14	35	116	49	59	120
170	Erosion (unspecified)	475	10	30	18	40	34	112	111	19	36	65
171	Abrasion	90	15	51	0	4	1	6	8	1	2	2
172	Cavitation	77	3	14	2	1	3	36	8	4	4	2
	Total	642	28	95	20	45	38	154	127	24	42	69
180	Seepage (unspecified)	1,322	71	94	85	90	50	239	230	132	67	264
181	Corrosion	37	0	7	1	9	1	1	6	6	4	2
182	Discoloration or staining	127	8	18	10	6	18	8	13	13	10	23
183	Exudation	6	3	0	0	0	0	0	3	0	0	0
184	Efflorescence	546	19	40	40	53	95	47	87	45	35	85
185	Incrustation	10	4	1	0	0	0	0	5	0	0	0
	Total	2,048	105	160	136	158	164	295	344	196	116	374

(Continued)

Table 9 (Concluded)

Deficiency Code	Deficiency Type	No.	LMVD	MRD	NAD	NCD	NED	NPD	ORD	SAD	SPD	SWD
			No. of Deficiencies Classified by Corps Division									
190	Spalling (unspecified)	1,791	112	177	122	310	95	142	390	116	86	241
191	Pitting	44	1	6	2	1	4	2	17	5	2	4
192	Popouts	101	3	33	2	11	0	1	25	1	9	16
	Total	1,936	116	216	126	322	99	145	432	122	97	261
	Overall Total	10,096	781	1042	502	1080	593	1113	2141	746	559	1539

(Sheet 3 of 3)

Table 10

Causes of Observed Deficiencies Classified as Light Damage

Deficiency Type	No.	No. of Specified Causes												Cause/ Deficiency
		Accidtl Loading	Chemical Reactions	Constr Faults	Maint Faults	Corrosion	Design Errors	Erosion	Settlmt or Movement	Shrinkage	Temp	Weath	Total	
Construction faults	172	0	0	102	5	0	1	1	0	0	0	0	109	0.63
Cracking	2473	4	3	7	0	0	11	0	9	202	37	5	278	0.11
Disintegration	166	0	12	3	1	0	0	0	0	0	0	9	25	0.15
Distortion or movement	465	8	0	6	0	0	1	1	151	0	0	1	168	0.36
Erosion	336	1	4	2	2	0	1	190	0	0	0	0	200	0.60
Joint sealant failure	61	0	0	2	0	0	0	0	0	0	0	1	3	0.05
Seepage	1563	0	7	11	0	24	4	0	1	3	1	0	51	0.03
Spalling	1258	42	0	16	4	3	3	0	7	0	4	9	88	0.07
Total	6494	55	26	149	12	27	21	192	168	205	42	25	922	

Table 11

Causes of Observed Deficiencies Classified as Moderate Damage

Deficiency Type	No.	No. of Specified Causes												Cause/ Deficiency
		Accidtl Loading	Chemical Reactions	Constr Faults	Maint Faults	Corrosion	Design Errors	Erosion	Settlmt or Movement	Shrinkage	Temp	Weath	Total	
Construction faults	25	0	0	17	0	0	0	0	0	0	0	0	17	0.68
Cracking	1094	11	9	9	1	1	7	0	10	40	9	10	107	0.10
Disintegration	154	1	14	2	0	0	1	0	0	2	1	15	36	0.23
Distortion or movement	166	8	0	3	0	0	0	1	67	0	0	0	79	0.48
Erosion	178	1	0	6	0	0	1	121	0	0	0	0	129	0.72
Joint sealant failure	100	0	0	3	0	0	0	0	1	0	0	2	6	0.06
Seepage	387	0	0	4	0	7	0	1	6	0	0	1	19	0.05
Spalling	508	25	4	9	1	2	0	0	9	0	0	19	69	0.14
Total	2612	46	27	53	2	10	9	123	93	42	10	47	462	

Table 12

Causes of Observed Deficiencies Classified as Severe Damage

Deficiency Type	No.	Accidtl Loading	Chemical Reactions	Constr Faults	Maint Faults	Corrosion	Design Errors	Erosion	Settlmt or Movement	Shrinkage	Temp	Weath	Total	Cause/ Deficiency
		No. of Specified Causes												
Construction faults	13	0	0	6	0	0	3	0	0	0	0	0	9	0.69
Cracking	141	4	2	2	0	0	5	0	4	0	0	6	23	0.16
Disintegration	89	3	4	0	0	0	5	0	0	0	0	17	29	0.33
Distortion or movement	65	7	0	1	0	1	1	1	16	0	0	0	27	0.42
Erosion	67	0	0	0	0	0	0	47	0	0	0	0	47	0.70
Joint sealant failure	42	0	0	0	0	0	0	0	2	0	0	0	2	0.05
Seepage	53	0	0	1	0	3	0	0	0	0	0	2	6	0.11
Spalling	99	15	1	0	0	0	1	0	1	0	0	13	31	0.31
Total	569	29	7	10	0	4	15	48	23	0	0	38	174	

Table 13

Causes of Observed Deficiencies Classified as Threatens Safety of Structure

Deficiency Type	No.	No. of Specified Causes												Cause/ Deficiency
		Accidtl Loading	Chemical Reactions	Constr Faults	Maint Faults	Corrosion	Design Errors	Erosion	Settlmt or Movement	Shrinkage	Temp	Weath	Total	
Construction faults	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Cracking	11	2	2	0	0	0	0	0	4	0	0	0	8	0.73
Disintegration	4	0	0	0	0	0	3	0	0	0	0	0	3	0.75
Distortion or movement	9	1	0	0	0	0	0	0	1	0	0	0	2	0.22
Erosion	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Joint sealant failure	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seepage	2	1	0	0	0	0	0	0	0	0	0	0	1	0.50
Spalling	3	0	0	1	0	0	0	0	0	0	0	0	1	0.33
Total	30	4	2	1	0	0	3	0	5	0	0	0	15	

Table 14

Summary of Cause-Deficiency Relations

Deficiency Type	No.	Accidtl Loading	Chemical Reactions	Constr Faults	Maint Faults	Corrosion	Design Errors	Erosion	Settlmt or Movement	Shrinkage	Temp	Weath	Total	Cause/ Deficiency
		No. of Specified Causes												
Construction faults	229	0	0	125	5	0	4	1	0	0	0	0	135	0.59
Cracking	3,842	21	16	18	1	1	23	0	27	242	46	21	416	0.11
Disintegration	435	4	30	5	1	0	9	0	0	2	1	41	93	0.21
Distortion or movement	747	24	0	10	0	1	2	3	235	0	0	1	276	0.37
Erosion	642	2	4	8	2	0	2	358	0	0	0	0	376	0.59
Joint sealant failure	217	0	0	5	0	0	0	0	3	0	0	3	11	0.05
Seepage	2,048	1	7	16	0	34	4	1	7	3	1	3	77	0.04
Spalling	1,936	82	5	26	5	5	4	0	17	0	4	41	189	0.10
Total	10,096	134	62	213	14	41	48	363	289	247	52	110	1573	

Table 15

Observed Deficiencies Classified as Light Damage in Various Structures

Deficiency Type	No.	Deficiencies in Various Types of Structures														
		Bridges			Dams			Locks			Powerhouses			Others		
		No.	% of Total	No. of Structures	No.	% of Total	No. of Structures	No.	% of Total	No. of Structures	No.	% of Total	No. of Structures	No.	% of Total	No. of Structures
Construction faults	172	16	4	15	126	3	91	21	2	17	9	2	7	0	0	0
Cracking	2473	216	49	131	1652	36	420	385	38	134	156	41	61	63	50	49
Disintegration	166	15	3	11	114	3	74	24	2	17	5	1	4	8	6	8
Distortion or movement	465	66	15	51	256	6	168	96	9	61	23	6	19	24	19	21
Erosion	336	5	1	4	302	7	184	22	2	17	5	1	5	0	0	0
Joint sealant failure	61	7	2	7	43	1	32	9	1	6	2	1	2	0	0	0
Seepage	1563	21	5	14	1189	26	350	210	21	103	130	34	53	13	10	12
Spalling	1258	94	21	78	846	19	337	244	24	108	55	14	34	19	15	18
Total	6494	440			4528			1011			385			127		

Table 16

Observed Deficiencies Classified as Moderate Damage in Various Structures

Deficiency Type	No.	Bridges No.	Bridges % of Total	Bridges No. of Structures	Dams No.	Dams % of Total	Dams No. of Structures	Locks No.	Locks % of Total	Locks No. of Structures	Powerhouses No.	Powerhouses % of Total	Powerhouses No. of Structures	Others No.	Others % of Total	Others No. of Structures
Construction faults	25	4	2	2	17	1	15	4	1	3	0	0	0	0	0	0
Cracking	1094	61	36	46	558	39	229	377	48	119	66	51	29	33	46	24
Disintegration	154	24	14	15	72	5	46	51	6	28	5	4	5	3	4	3
Distortion or movement	166	20	12	16	82	6	52	37	5	25	5	4	4	22	31	18
Erosion	178	1	1	1	160	11	75	14	2	12	1	1	1	0	0	0
Joint sealant failure	100	11	6	8	56	4	40	31	4	22	1	1	1	1	1	1
Seepage	387	3	2	2	256	18	132	92	12	57	33	25	20	3	4	3
Spalling	508	47	27	39	245	17	146	187	24	86	19	15	17	10	14	9
Total	2612	171			1446			793			130			72		

Table 17

Observed Deficiencies Classified as Severe Damage in Various Structures

Deficiency Type	No.	Bridges No.	Bridges % of Total	Bridges No. of Structures	Dams No.	Dams % of Total	Dams No. of Structures	Locks No.	Locks % of Total	Locks No. of Structures	Powerhouses No.	Powerhouses % of Total	Powerhouses No. of Structures	Others No.	Others % of Total	Others No. of Structures
Construction faults	13	1	3	1	3	1	3	6	2	4	0	0	0	3	17	3
Cracking	141	14	40	9	38	16	28	84	31	40	2	33	1	3	17	3
Disintegration	89	7	20	5	27	11	18	52	19	22	0	0	0	3	17	3
Distortion or movement	65	9	26	6	22	9	16	32	12	17	0	0	0	2	11	1
Erosion	67	0	0	0	59	25	31	6	2	4	1	17	1	1	6	1
Joint sealant failure	42	2	6	2	22	9	17	18	7	9	0	0	0	0	0	0
Seepage	53	1	3	1	35	15	24	17	6	9	0	0	0	0	0	0
Spalling	99	1	3	1	29	12	24	59	22	41	3	50	3	6	33	6
Total	569	35			235			274			6			18		

Table 18

Observed Deficiencies Classified as Threatens Safety of Structure in Various Structures

Deficiency Type	No.	Bridges No.	Bridges % of Total	Bridges No. of Structures	Dams No.	Dams % of Total	Dams No. of Structures	Locks No.	Locks % of Total	Locks No. of Structures	Powerhouses No.	Powerhouses % of Total	Powerhouses No. of Structures	Others No.	Others % of Total	Others No. of Structures
Construction faults	1	0	0	0	0	0	0	1	5	1	0	0	0	0	0	0
Cracking	11	0	0	0	5	45	2	6	32	4	0	0	0	0	0	0
Disintegration	4	0	0	0	0	0	0	4	21	2	0	0	0	0	0	0
Distortion or movement	9	0	0	0	5	45	3	4	21	1	0	0	0	0	0	0
Erosion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Joint sealant failure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Seepage	2	0	0	0	1	9	1	1	5	1	0	0	0	0	0	0
Spalling	3	0	0	0	0	0	0	3	16	2	0	0	0	0	0	0
Total	30	0			11			19			0			0		

Table 19

Summary of Observed Deficiencies in Various Structures

Deficiency			Deficiencies in Various Types of Structures									
			Bridges		Dams		Locks		Powerhouses		Others	
Type	No.	% of Total	No.	% of Total	No.	% of Total	No.	% of Total	No.	% of Total	No.	% of Total
Construction faults	229	2	21	3	146	2	32	2	9	2	3	1
Cracking	3,842	38	291	45	2253	36	852	41	224	43	99	46
Disintegration	435	4	46	7	213	3	131	6	10	2	14	6
Distortion or movement	747	7	95	15	365	6	169	8	28	5	48	22
Erosion	642	6	6	1	521	8	42	2	7	1	1	0
Joint sealant failure	217	2	20	3	121	2	58	3	3	1	1	0
Seepage	2,048	20	25	4	1481	24	320	15	163	31	16	7
Spalling	1,936	19	142	22	1120	18	493	24	77	15	35	16
Total	10,096		646		6220		2097		521		217	

Table 20

Locations in Dams of Observed Deficiencies Classified as Moderate Damage

Deficiency Type	No.	Unspec	Condu	DS Face	Drains	Flip Buckts	Gallrs	Gates	Gate Anchrg	Horiz Const Joints	Intake Struc	Monlth Joints	Piers or Abutms	Sluics
		No. of Deficiencies at Specified Locations												
Construction faults	17	0	6	2	0	0	1	0	0	1	0	1	1	0
Cracking	558	15	113	13	0	0	55	1	15	11	29	9	80	3
Disintegration	72	0	14	2	1	0	1	0	0	0	9	6	4	1
Distortion or movement	82	2	12	0	0	0	0	4	0	0	4	15	3	0
Erosion	160	0	32	0	1	1	0	5	0	1	7	9	5	4
Joint sealant failure	56	1	11	0	0	0	0	0	1	0	3	19	1	0
Seepage	256	5	45	5	6	0	29	35	1	21	18	46	15	5
Spalling	245	3	28	6	0	0	0	1	4	5	19	32	25	3
Total	1446	26	261	28	8	1	86	46	21	39	89	137	134	16

Type	No.	Splway Crest (Ogee)	Splway Face	Stillg Basin Baffls	Stillg Basin Floor	Stillg Basin Walls or Traing	US Face	Splway Monlth	Slope Paving	Outlet Works*	Apprch	End Sill	Horiz or Top Face
Construction faults	17	1	2	0	1	1	0	0	0	0	0	0	0
Cracking	558	32	52	0	12	57	15	11	1	3	8	3	20
Disintegration	72	3	11	1	3	10	0	2	1	0	0	1	2
Distortion or movement	82	5	2	0	2	23	1	2	0	1	2	1	3
Erosion	160	2	10	20	48	4	1	1	1	0	1	5	2
Joint sealant failure	56	2	9	0	4	3	0	1	1	0	0	0	0
Seepage	256	3	6	1	0	7	4	1	0	1	1	0	1
Spalling	245	15	34	2	9	24	6	10	0	2	4	2	11
Total	1446	63	126	24	79	129	27	28	4	7	16	12	39

* Separate from spillway.

Table 21

Observed Deficiencies in Dam Conduits

Deficiency			No. of Deficiencies Classified by Degree of Damage											
			Light			Moderate			Severe			Threatens Safety of Structure		
Type	No.	% of Total	No.	% of Total	No. of Structures	No.	% of Total	No. of Structures	No.	% of Total	No. of Structures	No.	% of Total	No. of Structures
Construction faults	47	4	36	5	27	6	2	5	0	0	0	0	0	0
Cracking	432	39	307	39	164	113	43	64	7	29	5	0	0	0
Disintegration	25	2	9	1	9	14	5	10	2	8	2	0	0	0
Distortion or movement	57	5	43	5	38	12	5	11	2	8	2	0	0	0
Erosion	121	11	78	10	67	32	12	21	8	33	5	0	0	0
Joint sealant failure	23	2	10	1	8	11	4	9	2	8	2	0	0	0
Seepage	253	23	203	26	126	45	17	35	2	8	2	0	0	0
Spalling	138	13	107	13	71	28	11	23	1	4	1	0	0	0
Total	1096		793			261			24			0		

Table 22

Types of Observed Deficiencies Which Have Been Repaired

Deficiency Type	No.	Light No.	Light % of Total	Light No. of Structures	Moderate No.	Moderate % of Total	Moderate No. of Structures	Severe No.	Severe % of Total	Severe No. of Structures	Threatens Safety of Structure No.	Threatens Safety of Structure % of Total	Threatens Safety of Structure No. of Structures	Overall No.	Overall % of Total
		Repairs Classified by Degree of Damage of Observed Deficiency													
Construction faults	229	13	7	12	3	1	2	2	2	2	0	0	0	18	3
Cracking	3,842	72	40	33	79	30	54	23	20	20	6	60	4	180	32
Disintegration	435	5	3	4	14	5	13	13	12	10	0	0	0	32	6
Distortion or movement	747	2	1	1	9	3	8	13	12	10	3	30	2	27	5
Erosion	642	12	7	11	47	18	24	25	22	17	0	0	0	84	15
Joint sealant failure	217	8	4	7	23	9	16	12	11	4	0	0	0	43	8
Seepage	2,048	17	9	14	27	10	24	11	10	5	0	0	0	55	10
Spalling	1,936	52	29	37	63	24	54	14	12	13	1	10	1	130	23
Total	10,096	181			265			113			10			569	

Table 23

Locations of Observed Deficiencies Which Have Been Repaired

Location		Repairs Classified by Degree of Damage of Observed Deficiency												Overall	
		Light			Moderate			Severe			Threatens Safety of Structure				
Type	No.	No.	% of Total	No. of Structures	No.	% of Total	No. of Structures	No.	% of Total	No. of Structures	No.	% of Total	No. of Structures	No.	% of Total
Bridges	683	14	8	11	22	8	17	8	7	5	0	0	0	44	8
Dams	6,518	115	64	68	139	52	80	53	46	33	3	30	2	310	54
Locks	2,227	43	24	15	88	33	51	51	45	22	7	70	5	189	33
Powerhouses	553	6	3	6	14	5	9	1	1	1	0	0	0	21	4
Others	224	3	2	3	2	1	2	1	1	1	0	0	0	6	1
Total	10,205	181			265			114			10			570	

APPENDIX A: DETAILED DESCRIPTIONS OF COMPUTER PROGRAMS DEVELOPED

Program ACHECK

Mode of Program: Time-sharing

Input Description: Time-sharing files, one per District, containing unformatted data that describe the location, operation, and physical features of each Corps of Engineers civil works structure.

Program Description: The program is an interactive program that reads time-sharing files containing the structure-description data base and checks for coding errors. The user requests a single District file for processing. There are 22 different data line reads used by the program to process data. Only five of these reads use an integer format. All other reads are alpha-formatted reads. Each structure name is read and written as output to the time-sharing terminal. If an error is encountered during execution of one of the integer reads, an error message is written to the terminal, and program execution is terminated. If no errors are encountered, only the structure names are written to the terminal.

An example run using Galveston District data file 'SWG' is shown below. Note that no errors were encountered.

```
*FRN R0SC45/ACHECK,R

ENTER 3-LETTER CODE FOR DISTRICT TO BE PROCESSED
=SWG
ADDICKS DAM
BARKER DAM
BRAZOS RIVER FLOODGATES AND LOCK
COLORADO RIVER EAST LOCK
COLORADO RIVER WEST LOCK

DO YOU WISH TO PROCESS ANOTHER FILE(Y OR N)
=N

*
```

Program MB

Mode of Program: Batch

Source Program File: BMERGE

Input Description: Time-sharing files, one per District, containing unformatted data that describe the location, operation, and physical features of each Corps of Engineers civil works structure.

Program Description: The program file is executed from time-sharing by giving the command

JRN ROSC45/MB,R

The program reads time-sharing files containing the structure-description data base, formats data, and writes formatted data to a saved tape. Data are processed alphabetically by Division, District, and structure names. The first line in each District file contains a '#' sign in column 1 followed by a 3-character Corps of Engineers abbreviation report code by which the dam is geographically located in accordance with Appendix B, Engineer Regulation (ER) 18-2-1, "Civil Works Information System," as follows:

LMVD

Memphis District	LMM
New Orleans District	LMN
St. Louis District	LMS
Vicksburg District	LMK

MRD

Kansas City District	MRK
Omaha District	MRO

NED

NAD

Baltimore District	NAB
New York District	NAN
Norfolk District	NAO
Philadelphia District	NAP

NCD

Buffalo District	NCB
Chicago District	NCC
Detroit District	NCE
Rock Island District	NCR
St. Paul District	NCS

NPD

Alaska District	NPA
Portland District	NPP
Seattle District	NPS
Walla Walla District	NPW

ORD

Huntington District	ORH
Louisville District	ORL
Nashville District	ORN
Pittsburgh District	ORP

(Continued)

POD

SAD

Charleston District	SAC
Jacksonville District	SAJ
Mobile District	SAM
Savannah District	SAS
Wilmington District	SAW

SPD

Los Angeles District	SPL
Sacramento District	SPK
San Francisco District	SPN

SWD

Albuquerque District	SWA
Ft. Worth District	SWF
Galveston District	SWG
Little Rock District	SWL
Tulsa District	SWT

Other data contained in a file are read according to the order and formats shown in the following:

- STRUCTURE NAME (45 characters)

  Official name of structure.

- PROJECT NAME (45 characters)

  Official name of project.

- LAKE NAME (45 characters)

  Official name of lake or reservoir.

- RIVER NAME (45 characters)

  Official name of river or stream on which the dam is built. If the stream is without name, the name of the tributary to the river into which it flows is entered; e.g., 'TR-COLORADO'. If offstream, the name of the river plus 'OFFSTREAM' is entered.

- STATE NAME, MILE NUMBER (2 characters, comma, 8 characters)

  2-character Postal Service abbreviation, and official river mileage for the structure. Abbreviations are as follows:

Alabama	AL	Maine	ME	Pennsylvania	PA
Alaska	AK	Maryland	MD	Rhode Island	RI
Arizona	AZ	Massachusetts	MA	South Carolina	SC

(Continued)

Arkansas	AR	Michigan	MI	South Dakota	SD
California	CA	Minnesota	MN	Tennessee	TN
Colorado	CO	Mississippi	MS	Texas	TX
Connecticut	CT	Missouri	MO	Utah	UT
Delaware	DE	Montana	MT	Vermont	VT
District of Columbia	DC	Nebraska	NE	Virginia	VA
Florida	FL	Nevada	NV	Washington	WA
Georgia	GA	New Hampshire	NH	West Virginia	WV
Hawaii	HI	New Jersey	NJ	Wisconsin	WI
Idaho	ID	New Mexico	NM	Wyoming	WY
Illinois	IL	New York	NY	Samoa	AS
Indiana	IN	North Carolina	NC	Puerto Rico	PR
Iowa	IA	North Dakota	ND	Territories	TT
Kansas	KS	Ohio	OH	Virgin Islands	VI
Kentucky	KY	Oklahoma	OK	Guam	GU
Louisiana	LA	Oregon	OR		

- DOWNSTREAM CITY (45 characters)

  Name of nearest downstream city, town, or village of such size as can be found on a general map of the area or state.

- SEISMIC ZONE, DOWNSTREAM HAZARD (1 character, comma, 1 character)

  Seismic zone code defined and delineated in ER 1110-2-1806, "Earthquake Design and Analysis for Corps of Engineers Dams," and hazard potential category. The seismic zone code (0 through 4) indicates probability of seismic damage as follows:

Code	Damage	Coefficient
0	None	0
1	Minor	0.025
2	Moderate	0.05
3	Major	0.10
4	Great	0.15

The hazard potential category (1 through 3) is that which most closely represents hazard potential to the downstream area resulting from failure or misoperation of the dam or facilities as follows:

Category	Hazard Potential	Consequences: Loss of Life	Consequences: Economic Loss
1	Low	None expected	Minimal
2	Significant	Few	Appreciable
3	High	More than a few	Excessive

- CATEGORY, COMPLETION DATE (1 character, comma, 4 characters)

  Category or status of dam, and year when main structure was completed and ready for use. Categories are as follows:

D	dam being designed by the Corps
U	dam under construction by the Corps
C	Corps-built dam being managed by the Corps
O	Corps-built dam being managed by others
S	Non-Corps dam with purchased flood control storage

- OWNER (35 characters)

  Name of owner, abbreviated as necessary. Federal agencies are uniformly designated by major and minor abbreviations according to the following list:

Federal Agency Name	Major	Minor
International Boundary and Water Commission	IBWC	
US Department of Agriculture		
Soil Conservation Service	USDA	SCS
Forest Service	USDA	FS
US Department of Energy		
Federal Energy Regulatory Commission	DOE	FERC
Tennessee Valley Authority	TVA	
US Department of Interior		
Bureau of Sport Fisheries and Wildlife	DOI	BSFW
Geological Survey	DOI	GS
Bureau of Land Management	DOI	BLM
Water and Power Resources Services	DOI	WPRS
Bureau of Indian Affairs	DOI	BIA
National Park Service	DOI	NPS
US Department of Labor		
Mine Safety and Health Administration	DOL	MSHA
US Department of Defense		
US Army	DOD	USA
US Navy	DOD	USN
US Air Force	DOD	USAF
US Marine Corps	DOD	USMC
US Department of Justice		
Bureau of Prisons	DOJ	BOP
US Army Corps of Engineers	DAEN	*
Others not listed above	USA	Agency Name

* 3-character Corps of Engineers abbreviation report code is used for the minor abbreviation.

- OPERATOR (35 characters)

  Name of organization, other than the owner, having regulatory authority, operational control, or surveillance responsibilities over operation of the dam.

- PURPOSE (1 character for each purpose separated by commas)

  Array of 1-character codes that describe the purpose for which the reservoir is used, as follows:

I	irrigation
H	hydroelectric
F	flood control
D	debris control
O	other
S	water supply
R	recreation
N	navigation
P	stock or small farm pond

  Up to 10 purposes can be entered in order of relative decreasing importance.

- TYPE OF DAM (1 character for each type separated by commas)

  Array of 1-character codes that describe the type(s) of construction used for the dam, as follows:

E	earthfill	B	buttress
R	rockfill	A	arch
G	gravity	M	multi-arch

  Up to 6 types can be entered in order of relative decreasing importance.

- STRUCTURAL HEIGHT OF DAM, CREST LENGTH, STORAGE CAPACITY, SPILLWAY DISCHARGE, SPILLWAY TYPE (45 characters, values separated by commas)

  Contains:

  (1) Structural height of the dam, to the nearest foot; defined as the overall vertical distance from the lowest point of the foundation surface to the top of the dam.

  (2) Crest length of the dam, to the nearest foot; defined as the total horizontal distance measured along the axis at the elevation of the top of the dam between abutments or ends of the dam. Note that this includes spillway width, powerhouse sections, and navigation locks where they form a continuous part of the dam water-retaining structure. Detached spillways, locks, and powerhouses are not included.

(3) Acre-feet of storage for the maximum storage; defined as the total storage space in a reservoir below the maximum attainable water elevation, including any surcharge storage.

(4) Number of cubic feet per second which the spillway is capable of discharging when the reservoir is at its maximum designed water surface elevation.

(5) 1-character code that describes the type of spillway and is as follows:

C controlled
U uncontrolled
N none

- OUTLET TYPE (45 characters)

  Description of the outlets that exist.

- NUMBER OF LOCK CHAMBERS (1 integer)

  1-digit number indicating the number of existing navigation locks for the project. Maximum number of locks is four (4). Entry of '9' indicates number is unknown.

- LOCK LENGTH (23 characters, values separated by commas)

  Contains to the nearest foot the length of the navigation lock(s). As many as four (4) locks per structure are possible.

- LOCK WIDTH (23 characters, values separated by commas)

  Contains to the nearest foot the width of the navigation lock(s). As many as four (4) locks per structure are possible.

- LOCK LIFT (23 characters, values separated by commas)

  Contains to the nearest foot the mean lock lift for the normal operating conditions of the lock. Lock lift is defined as the difference in elevation between the upper and lower pools. As many as four (4) locks per structure are possible.

- CONCRETE DESCRIPTION OR COMMENTS (four 70-character lines)

  Narrative describing what portions of structure are concrete, and any other necessary comments.

Output data are written to a saved tape in the following order and format:

Description	Write Field
Output Per District	
District ID flag	'#' in column 1 followed by 3-character District code
Output Per Structure	
Structure name	45 characters
Project name	45 characters
Lake name	45 characters
River name	45 characters
Downstream name	45 characters
State name; mile number; seismic zone; downstream hazard category; completion date	2 characters, space; 9 characters, space; 1 character, space; 1 character, space; 1 character, space; 4 integers
Owner, operator	35 characters, space; 35 characters
Purposes	Ten 1-character values separated by spaces
Dam type; structural height, crest length, storage capacity, spillway discharge, spillway type	Six 1-character values separated by spaces for dam type; (followed by a space); four 10-character values separated by spaces for project description (followed by a space); one 1-character value for spillway type
Number of lock chambers and lock lengths, widths, and lifts	2 integers, space; twelve 5-character values separated by spaces
Concrete description or comment statements	Four lines, each containing a space in column 1 followed by a 45-character value

The saved tape generated from the program execution is later used by program JCLCONT to list the data base in table form.

The data base is maintained by updating the contents of the individual District time-sharing files and rerunning programs MB and JCLCONT.

Program JCLCONT

Mode of Program: Batch

Source Program File: CONTROL

Input Description: Output tape from execution of program MB that contains formatted data describing the location, operation, and physical features of Corps of Engineers civil works structures.

Program Description: The program file is executed from time-sharing by giving the command

OLD RØSC45/JCLCONT,R

changing the input tape number to that of the saved tape from the execution of program MB, and giving the command 'JRN'. The program reads saved tape, reformats data into table form, writes tables to a saved tape, and directs output to the page printer. Data are read by the program in the same order and format as written by program MB. Division and District names are expanded from the 3-letter codes and written into tables. Category and purposes of structure, types of dam, and types of spillway are expanded from their 1-letter codes and written into tables. The following three output options are available:

- OPTION 1: A 1-page table for each structure that describes the location, operation, and physical features of the structure.
- OPTION 2: An alphabetical listing by structure name of all structures in the data base, each structure being allocated one line.
- OPTION 3: Summary tables based on the physical characteristics of the structure:

Table 1	Overall Summary by Division
Table 2	Summary Within Each Division
Table 3	Summary Within Each District

To select option(s), enter the number(s) of the option(s) selected in the 'OPT' data statement of source program file CONTROL. Options may be selected in any order. A '9' must be entered after the last option selected to terminate the program. The output for all options is written to a saved tape and to a temporary tape. The temporary tape is used to produce a listing of output from the page printer. An additional copy of output can be made by executing program JCLPCONT.

Program JCLPCONT

Mode of Program: Batch

Input Description: Output tape from execution of program JCLCONT that contains tables of formatted data describing the location, operation, and physical features of Corps of Engineers civil works structures.

Program Description: The program file is executed from time-sharing by giving the command

OLD ROSC45/JCLPCONT,R

changing the input tape number to that of the saved tape from the execution of program JCLCONT, and giving the command 'JRN'. The program reads saved tape and directs output to the page printer. The program reads a single line of data from the saved tape and writes data lines to a temporary tape using a 132-character format. When all data have been processed, the temporary tape is used to generate a listing of output from the page printer. The output data consist of three types and depend on the option(s) selected in execution of program MB. Output data types are as follows:

- OPTION 1: A 1-page table for each structure that describes the location, operation, and physical features of the structure.
- OPTION 2: An alphabetical listing by structure name of all structures in the data base, each structure being allocated one line.
- OPTION 3: Overall, Division, and District summary tables based on the physical characteristics of the structure.

Program SNAME

Mode of Program: Time-sharing

Input Description: Pairs of time-sharing files, one containing structure-description data and one containing damage and repair data.

Program Description: The program is an interactive time-sharing program in which the structure names are sorted in pairs, one from the structure-description data base and one from the damage and repair data base, for comparison with each other. Both structure names are written to an output file along with an error message when the two names are not identical. The output file can be listed at the terminal or dumped to the page printer using the 'XPRINT' or 'PRINT' time-sharing command.

An example run using the Buffalo and Alaska District files is shown below. Note that no errors were encountered.

Execution

```
*FRN ROSC45/SNAME,R

ENTER NAME OF OUTPUT FILE
=SO

ENTER NUMBER OF DISTRICTS TO BE SEARCHED(MAX. 35)
=2

ENTER 3-LETTER CODE FOR EACH DISTRICT REQUEST
=NCB NPA

FILE /CNCB     / ATTACHED
FILE /INCB     / ATTACHED

FILE /CNPA     / ATTACHED
FILE /INPA     / ATTACHED

*
```

Output

```
*LIST SO
```

(Continued)

```
*****************************************************************************
**************
                                            EXECUTION OF PROGRAM 'SNAME'
*****************************************************************************
**************


 NCB BLACK ROCK LOCK
 NCB BLACK ROCK LOCK

 NCB MT MORRIS DAM
 NCB MT MORRIS DAM

 NCB ONONDAGA DAM
 NCB ONONDAGA DAM

 NCB


 NPA BRADLEY DAM
 NPA BRADLEY DAM

 NPA CHENA RIVER LAKES DAM
 NPA CHENA RIVER LAKES DAM

 NPA SNETTISHAM DAM
 NPA SNETTISHAM DAM

 NPA
```

Program ICHECK

Mode of Program: Time-sharing

Input Description: Time-sharing files, one per District, containing unformatted data codes that denote the observation, cause, location, and degree of damage and the material, technique, and performance of repair.

Program Description: The program is an interactive program that reads time-sharing files containing the damage and repair data base and checks for coding errors. The user requests a single District file for processing. Each line of the data file is read using a 70-character format. The first character of the line is decoded. If the first character is '#', the line of data is decoded into a 3-letter District code and a structure name. If the first character is '*', the line of data is decoded as a report identifier. If the first character is neither '#' nor '*', the line of data is processed as damage and repair codes. These codes are sorted according to the following categories of ranges of codes:

100-199	observed damage
200-299	causes of damage
300-399	location of damage
401-405	degree of damage
500-599	repair material
600-699	repair technique
701-705	performance of repair

The program checks for the following errors:

(1) Incorrect 3-letter District code.

(2) Undefined code which does not match any of the presently defined codes.

(3) Two codes within a data line that fall within the same category range.

Messages for the above errors are printed to the time-sharing terminal as errors are encountered. The message for error (1) above includes the District code and structure name. The messages for errors (2) and (3) above include the District code, structure name report identifier, beginnning range number for the category in which the error was encountered, and data line containing the error. The program continues processing lines of data until the end of the file is reached. At that time, another District can be attached and processed. This procedure can be repeated as many times as desired.

An example run using the Louisville District data file 'ORL' as input is shown below. Note that no errors were encountered.

```
*FRN R0SC45/ICHECK,R

ENTER 3-LETTER CODE FOR DISTRICT TO BE PROCESSED
=ORL

NUMBER OF REPORTS REVIEWED   =        117
NUMBER OF REPORTS NOT FOUND =         39
TOTAL NUMBER OF REPORTS      =        156
DO YOU WISH TO PROCESS ANOTHER FILE?(Y OR N)
=N

*
```

Program DEFECTS

Mode of Program: Batch

Source Program File: R

Input Description: Time-sharing files, one per District, containing unformatted data codes that denote the observation, cause, location, and degree of damage and the material, technique, and performance of repair.

Program Description: The program is executed from time-sharing by giving the command

JRN ROSC45/DEFECTS,R

The program reads time-sharing files containing the damage and repair data base, interprets codes into alpha descriptions, writes tables of inspection reports and tables of sums of damage and repair codes to a saved tape, and directs output to the page printer. The data are processed alphabetically by Division, District, and structure. Each line of data is read using a 70-character format. The first character of the line is decoded. If the first character is '#', the line of data is decoded into a 3-letter District code and a structure name. If the first character is '*', the line of data is decoded as a report identifier. If the first character is neither '#' nor '*', the line of data is processed as damage and repair codes. The codes are sorted according to the following categories of ranges of codes:

100-199	observed damage
200-299	cause of damage
300-399	location of damage
401-405	degree of damage
500-599	repair material
600-699	repair technique
701-705	repair performance

A description of individual damage and repair numbers is presented in Appendix B.

The input data are processed to generate tables of alpha descriptions of inspection data and tables of sums of occurrences of codes. Alpha descriptions are listed by structure name and grouped according to report identifiers. A minimum of one page of alpha output per structure is generated. Sums of occurrences are listed for each structure, District, and Division and for the Corps as a whole. Two pages of output are generated for each: page 1 contains the sums of occurrences of damage codes; page 2 contains the sums of occurrences of repair codes. Codes with zero occurrence are omitted from output.

The output is written to a saved tape. The data are partitioned into three groups:

(1) Alpha descriptions of inspection data.

(2) Sums of occurrences of codes by structure.

(3) Sums of occurrences of codes by District, Division, and Corps-wide.

The output data are also written to a temporary tape for producing a listing of output at the page printer. An additional page-print copy of output tables can be made by executing program PTAPE.

The data base is maintained by updating the contents of the individual District time-sharing files and rerunning program DEFECTS.

Program PTAPE

Mode of Program: Batch

Input Description: Output tape from execution of program DEFECTS that contains tables of inspection reports and tables of sums of damage and repair codes.

Program Description: The program file is executed from time-sharing by giving the command

OLD ROSC45/PTAPE,R

changing the input tape number to that of the saved tape from the execution of program DEFECTS, and giving the command 'JRN'.

The program reads saved tape and directs output to the page printer. The program reads a single line of data from the saved tape and writes the data line to a temporary tape using a 132-character format. When all the data have been processed, the temporary tape is used to generate a listing of output from the page printer.

Output data are partitioned into three groups:

(1) Alpha descriptions of inspection data.

(2) Sums of occurrences of codes by structure.

(3) Sums of occurrences by District, Division, and Corps-wide.

Program SEARCH

Mode of Program: Time-sharing

Input Description: District time-sharing files containing unformatted data codes that denote the observation, cause, location, and degree of damage and the material, technique, and performance of repair.

Program Description: The program is an interactive program that reads time-sharing file(s) containing the damage and repair data base, searches for string(s) of code(s), and writes data for any matches found to a time-sharing output file. The user can request up to five searches of data per run. The user enters the desired code(s) for each search. A temporary output file is created for each search requested. The number of Districts to be searched is interactively entered, followed by a 3-letter District code for each District. To process all files in the data base, the user can enter the number '35' for the number of Districts to be searched.

Each line of data file is read using a 70-character format. The first character of the line is decoded. If the first character is '#', the line of data is decoded into a 3-letter District code and a structure name. If the first character is '*', the line of data is decoded as a report identifier. If the first character is neither '#' nor '*', the line of data is processed as damage and repair codes.

As each data line is read, the codes contained in the data line are checked to see if they match the search code(s). If a match is found, a 3-letter District code, structure name, report identifier, and the data line are written to the corresponding output file. The output file can be listed at the terminal or dumped to the printer through an 'XPRINT' or a 'PPRINT' time-sharing command.

An example run using Buffalo District file 'INCB' as input is shown below:

Input

```
LIST INCB

#NCB BLACK ROCK LOCK
*NO REPORT FOUND
#NCB MT MORRIS DAM
*NO REPORT FOUND FOR REPORT 1
*REPORT 2 SEP 73
190 335 402
190 337 402
190 330 402
192 337 402
190 343 402
120 321 402
190 321 402
170 262 321 402
```

(Continued)

```
*REPORT 3 NOV 78
*NO DEFICIENCIES FOUND
#NCB ONONDAGA DAM
*REPORT 1 OCT 67
126 337 402
121 337 402
120 337 402
*REPORT 2 SEP 73
*NO DEFICIENCIES FOUND


*
```

Execution

```
*FRN R0SC45/SEARCH,R

 ENTER NUMBER OF SEARCHES TO BE MADE(MAX 5)
=1


ENTER CODE(S) FOR SEARCH #1
=337

FOR SEARCH #1

ENTER NAME OF OUTPUT FILE
=S337

ENTER NUMBER OF DISTRICTS TO BE SEARCHED(MAX. 35)
=1

ENTER 3-LETTER DISTRICT CODE FOR EACH REQUEST
=NCB


FILE /INCB      / ATTACHED

NUMBER OF REPORTS REVIEWED  =           4
NUMBER OF REPORTS NOT FOUND =           2
TOTAL NUMBER OF REPORTS     =           6



**************************************************************
RESULTS OF SEARCH #1 FOR CODES:     337
NUMBER OF MATCHED CODES =       5


DO YOU WISH TO PROCESS ANOTHER FILE?(Y OR N)
=N

*
```

Output

```
*LIST S337

1

#NCB MT MORRIS DAM
*REPORT 2 SEP 73
   190   337   402      0      0      0      0
   192   337   402      0      0      0      0

#NCB ONONDAGA DAM
*REPORT 1 OCT 67
   126   337   402      0      0      0      0
   121   337   402      0      0      0      0
   120   337   402      0      0      0      0
1


 ***********************************************************
 RESULTS OF SEARCH #1 FOR CODES:     337
 NUMBER OF MATCHED CODES =       5


*
```

Program SEARCH2

Mode of Program: Time-sharing

Input Description: Time-sharing file from execution of program SEARCH, SEARCH2, or SEARCH3 containing data that denote the observation, cause, location, and degree of damage and the material, technique, and performance of repair.

Program Description: The program is an interactive program that reads time-sharing files output from execution of program SEARCH, SEARCH2, or SEARCH3; searches data for string(s) of code(s); and writes data for any matches found to a time-sharing output file. The user can request up to five searches of data per run. The user enters the desired codes for each search. A temporary file is created for each search requested.

Each line of the data file is read using a 70-character format. The first character of the line is decoded. If the first character of the line is '#', the line of data is decoded into a 3-letter District code and a structure name. If the first character is '*', the line of data is decoded as a report identifier. If the first character is neither '#' nor '*', the line of data is processed as damage and repair codes. The program ignores any line of damage and repair data in which a read error occurs or the first code number on the data line is less than 100. This procedure allows the program to skip comment and blank lines in the data file.

As each data line is read, the codes contained in the data line are checked to see if they match the search code(s). If a match is found, the associated 3-letter District code, structure name, report identifier, and data line are written to the corresponding temporary file. When all data have been processed, the temporary files are rewritten to a single permanent file. The permanent file can then be listed at the terminal or dumped to the printer through an 'XPRINT' or a 'PPRINT' time-sharing command.

An example run using data obtained from a previous search of Buffalo District file 'INCB' as input is shown below:

Input

```
*LIST S337

1

#NCB MT MORRIS DAM
*REPORT 2 SEP 73
   190  337  402     0     0     0     0
   192  337  402     0     0     0     0
```

(Continued)

```
#NCB ONONDAGA DAM
*REPORT 1 OCT 67
   126  337  402     0     0     0     0
   121  337  402     0     0     0     0
   120  337  402     0     0     0     0
1

 *****************************************************************
 RESULTS OF SEARCH #1 FOR CODES:      337
 NUMBER OF MATCHED CODES =       5

*
```

Execution

```
*FRN R0SC45/SEARCH2,R

 ENTER NUMBER OF SEARCHES TO BE MADE(MAX 5)
=1
ENTER CODE(S) FOR SEARCH #1
=121

ENTER NAME OF OUTPUT FILE
=S337A

ENTER NAME OF INPUT FILE
=S337

FILE 'S337     ' ATTACHED



*****************************************************************
RESULTS OF SEARCH #1 FOR CODES:     121
NUMBER OF MATCHED CODES =       1
NO. STR. W/MATCHED CODES =       1

DO YOU WISH TO LIST OUTPUT(Y OR N)
=Y

NUMBER OF REPORTS REVIEWED  =         2
NUMBER OF REPORTS NOT FOUND =         0
TOTAL NUMBER OF REPORTS     =         2
```

(Continued)

```
****************************************************************
RESULTS OF SEARCH #1 FOR CODES:     121
NUMBER OF MATCHED CODES =       1
NO. STR. W/MATCHED CODES =       1


#NCB ONONDAGA DAM
*REPORT 1 OCT 67
  121  337  402     0     0     0     0



DO YOU WISH TO PROCESS ANOTHER FILE?(Y OR N)
=N

*
```

Program SEARCH3

Mode of Program: Time-sharing

Input Description: Time-sharing file from execution of program SEARCH, SEARCH2, or SEARCH3 containing data that denote the observation, cause, location, and degree of damage and the material, technique, and performance of repair.

Program Description: The program is an interactive program that reads time-sharing files output from execution of program SEARCH, SEARCH2, or SEARCH3; searches data for range(s) of code(s); and writes data for any matches found to a time-sharing output file. The user can request up to five searches of data per run. The user enters the desired ranges of codes for each search. A temporary file is created for each search requested.

Each line of data file is read using a 70-character format. The first character of the line is decoded. If the first character is '#', the line of data is decoded into a 3-letter District code and a structure name. If the first character is '*', the line of data is decoded as a report identifier. If the first character is neither '#' nor '*', the line of data is processed as damage and repair codes. The program ignores any line of damage and repair data in which a read error occurs or the first code number on the data line is less than 100. This procedure allows the program to skip comment and blank lines in the data file.

As each data line is read, the codes contained in the data line are checked to see if they match the search codes. If a match is found, the associated 3-letter District code, structure name, report identifier, and the data line are written to the corresponding temporary file. When all the data have been processed, the temporary files are rewritten to a single permanent file. The permanent file can be listed at the terminal or dumped to the printer through an 'XPRINT' or a 'PPRINT' time-sharing command.

An example run using data obtained from a previous search of Buffalo District file 'INCB' as input is shown below.

Input

```
LIST S337

1

#NCB MT MORRIS DAM
*REPORT 2 SEP 73
   190  337  402     0     0     0     0
   192  337  402     0     0     0     0
```

(Continued)

```
#NCB ONONDAGA DAM
*REPORT 1 OCT 67
   126  337  402     0     0     0     0
   121  337  402     0     0     0     0
   120  337  402     0     0     0     0
1


 ************************************************************
 RESULTS OF SEARCH #1 FOR CODES:     337
 NUMBER OF MATCHED CODES =       5


*
```

<u>Execution</u>

```
*FRN ROSC45/SEARCH3,R

 ENTER NUMBER OF SEARCHES TO BE MADE(MAX 5)
=1
ENTER RANGES OF CODE(S)  FOR SEARCH #1
=120 130

ENTER NAME OF OUTPUT FILE
=S337B

ENTER NAME OF INPUT FILE
=S337

FILE 'S337     ' ATTACHED



************************************************************
RESULTS OF SEARCH #1 FOR CODES:
120 - 130
NUMBER OF MATCHED CODES =       3
NO. STR. W/MATCHED CODES =       1

DO YOU WISH TO LIST OUTPUT(Y OR N)
=Y

NUMBER OF REPORTS REVIEWED   =          2
NUMBER OF REPORTS NOT FOUND =          0
TOTAL NUMBER OF REPORTS      =          2
```

(Continued)

```
*************************************************************
RESULTS OF SEARCH #1 FOR CODES:
120 - 130
NUMBER OF MATCHED CODES =        3
NO. STR. W/MATCHED CODES =       1


#NCB ONONDAGA DAM
*REPORT 1 OCT 67
  126  337  402    0    0    0    0
  121  337  402    0    0    0    0
  120  337  402    0    0    0    0



DO YOU WISH TO PROCESS ANOTHER FILE?(Y OR N)
=N

*
```

APPENDIX B: LISTING
OF DAMAGE AND REPAIR CODES,
TYPICAL DATA SHEET,
AND DEFINITIONS OF
OBSERVED DEFICIENCIES

100. Observed Deficiencies

110. Construction faults (unspecified)
    - 111. Bug holes
    - 112. Cold joints
    - 113. Exposed reinforcing steel
    - 114. Honeycombing
    - 115. Irregular surface

120. Cracking (unspecified)
    - 121. Checking or crazing
    - 122. D-cracking
    - 123. Diagonal
    - 124. Hairline
    - 125. Longitudinal
    - 126. Map or pattern
    - 127. Random
    - 128. Transverse
    - 129. Vertical
    - 130. Horizontal

140. Disintegration (unspecified)
    - 141. Blistering
    - 142. Chalking
    - 143. Delamination
    - 144. Drummy area
    - 145. Dusting
    - 146. Peeling
    - 147. Scaling
    - 148. Weathering

155. Distortion or movement (unspecified)
    - 156. Buckling
    - 157. Curling
    - 158. Faulting
    - 159. Settling
    - 160. Tilting
    - 161. Warping

170. Erosion (unspecified)
    - 171. Abrasion
    - 172. Cavitation

175. Joint sealant failure

180. Seepage (unspecified)
    - 181. Corrosion
    - 182. Discoloration or staining
    - 183. Exudation
    - 184. Efflorescence
    - 185. Incrustation

190. Spalling (unspecified)
    - 191. Pitting
    - 192. Popouts

200. Causes

210. Accidental loading (unspecified)
    - 211. Earthquake
    - 212. Impact
    - 213. Overloading

220. Chemical reactions (unspecified)
    - 221. Acid attack
    - 222. Aggressive water
    - 223. Alkali-carbonate rock reaction
    - 224. Alkali-silica reaction
    - 225. Chemical attack (type unknown)
    - 226. Sulfate attack

230. Construction faults

235. Maintenance faults

240. Corrosion

250. Design errors (unspecified)
    - 251. Faulty design details
    - 252. Under-designed

260. Erosion (unspecified)
    - 261. Abrasion
    - 262. Cavitation

270. Settlement or movement

275. Shrinkage (unspecified)
    - 276. Drying
    - 277. Plastic

280. Temperature (unspecified)
    - 281. Externally generated
    - 282. Fire
    - 283. Internally generated

290. Weathering (unspecified)
    - 291. Freezing and thawing

300. Locations

310. Bridges (unspecified)

 311. Decks
 312. Expansion joints
 313. Piers, pedestals, or abutments
 314. Parapet walls
 315. Bearings

320. Dams (unspecified)

 321. Conduits
 322. Downstream face
 323. Drains
 324. Flip bucket
 325. Galleries
 326. Gates
 327. Gate anchorages
 328. Horizontal construction joints
 329. Intake structures
 330. Monolith joints
 331. Piers or abutments
 332. Sluices
 333. Spillway crest (ogee)
 334. Spillway face
 335. Stilling basin, baffles
 336. Stilling basin, floor
 337. Stilling basin, walls
 338. Upstream face
 339. Spillway monolith
 340. Slope paving
 341. Outlet works (separate from spillway)
 342. Approach
 343. End sill
 344. Horizontal (top face)

345. Navigation locks (unspecified)

 346. Chamber walls, vertical surfaces
 347. Chamber walls, horizontal surfaces
 348. Emptying and filling conduits
 349. Floor
 350. Galleries
 351. Gates
 352. Guard walls
 353. Guide walls
 354. Horizontal construction joints
 355. Monolith joints
 356. Sill blocks
 357. Lock monoliths

365. Powerhouses (unspecified)

 366. Bridge crane
 367. Draft tubes
 368. Exterior walls
 369. Floors
 370. Horizontal construction joints
 371. Intake structure
 372. Interior walls
 373. Roof
 374. Tailrace deck
 375. Vertical construction joints
 376. Walls
 377. Penstock
 378. Galleries

390. Other

 391. Esplanade
 392. Fish facilities
 393. Floodwalls
 394. Retaining walls
 395. Dikes

400. Degree of Damage

401. Not specified

402. Light

403. Moderate

404. Severe

405. Threatens safety of structure

500. Repair Materials

500. Unspecified

510. Concrete (unspecified)

- 511. Conventional (portland cement)
- 512. Fiber reinforced (glass)
- 513. Fiber reinforced (steel)
- 514. Preplaced aggregate
- 515. Polymer (PC)
- 516. Polymer impregnated (PIC)
- 517. Polymer portland cement (PPCC)

520. Epoxy

525. Grout (unspecified)

- 526. Chemical
- 527. Portland cement
- 528. Epoxy

530. Joint sealants (unspecified)

- 531. Field-molded mastic
- 532. Field-molded thermoplastic (hot applied)
- 533. Field-molded thermoplastic (cold applied)
- 534. Field-molded thermosetting (chemical curing)
- 535. Field-molded thermosetting (solvent release)
- 536. Preformed compression seal

540. Mortar (unspecified)

- 541. Epoxy
- 542. Portland cement

545. Paint

550. Shotcrete (uspecified)

- 551. Conventional (portland cement)
- 552. Fiber reinforced (glass)
- 553. Fiber reinforced (steel)

560. Steel (unspecified)

- 561. Deformed reinforcing bars
- 562. Mesh
- 563. Plate
- 564. Posttensioning strands or bars
- 565. Rock anchors
- 566. Magnesium oxide anodes

570. Surface sealants or coatings (unspecified)

- 571. Acrylics
- 572. Bituminous
- 573. Linseed oil
- 574. Neoprene
- 575. Urethane

580. Waterstops (unspecified)

- 581. Metal
- 582. Preformed (PVC)
- 583. Rubber

590. Asphalt

600. Repair Techniques

600. Unspecified

603. Brush-on

604. Cathodic protection

606. Conventional forming and placing

609. Drilling and plugging

612. Dry pack

615. Injection

618. Jacketing

621. Judicious neglect

624. Overlay

627. Polymer impregnation

630. Posttensioning

633. Precast elements

636. Preplaced aggregate concrete

639. Roll-on

642. Route and seal

645. Shotcrete (dry-mix)

648. Shotcrete (wet-mix)

651. Slabjacking

654. Spray-on

657. Stitching

658. Sawing for stress relief

660. Trowel-on

663. Underwater placement (preplaced aggregate)

666. Underwater placement (pump)

669. Underwater placement (tremie)

700. Repair Performance

701. Not specified

702. Good

703. Fair

704. Poor

705. Failed

Typical Inspection Data Sheet

A. 3-letter District code, structure name:

LMK Arkabutla Dam

B. Inspection report number, date:

* Report 2 Nov 74

C. Damage and repair codes:

Deficiency				Repair		
Observation	Cause	Location	Degree of Damage	Material	Technique	Performance
180		330	403			
175		321	403	536	600	701
171	261	336	403	520	600	701
175		330	403			
175		334	404	536	600	701
180		343	402			

100. Observations (Definitions)

110. Construction faults (unspecified) - Deficiencies resulting from improper construction practices.

111. Bug holes - Small regular or irregular cavities, usually not exceeding 15 mm in diameter, resulting from entrapment of air bubbles in the surface of formed concrete during placement and compaction.

112. Cold joint - A joint or discontinuity resulting from a delay in placement of sufficient time to preclude a union of the material in two successive lifts.

113. Exposed reinforcing steel - Improper positioning of reinforcing steel resulting in lack of concrete cover.

114. Honeycomb - Voids left in concrete due to failure of the mortar to effectively fill the spaces among coarse aggregate particles.

115. Irregular surface - Surface is not flat; does not lie within a plane.

120. Cracking (unspecified) - Unplanned discontinuity resulting from restrained movement.

121. Checking - Development of shallow cracks at closely spaced but irregular intervals on the surface of mortar or concrete.

122. D-cracking - The progressive formation on a concrete surface of a series of fine cracks at rather close intervals, often of random patterns, but in slabs on grade paralleling edges, joints, and cracks and usually curving across slab corners.

123. Diagonal - An inclined crack caused by shear stress, usually at about 45 degrees to the neutral axis of a concrete member; or a crack in a slab, not parallel to lateral or longitudinal dimension.

124. Hairline - Small cracks of random pattern in an exposed concrete surface.

125. Longitudinal - Cracks that develop along the long axis of a member.

126. Map/pattern - Fine openings on concrete surfaces in the form of a pattern; resulting from a decrease in volume of the material near the surface, or increase in volume of the material below the surface, or both.

127. Random - Isolated cracks of varying direction.

128. Transverse - Cracks that develop at right angles to the long direction of the member.

129. Vertical - Cracks generally oriented in the vertical direction.

130. Horizontal - Cracks generally oriented in the horizontal direction.

140. Disintegration (unspecified) - Deterioration into small fragments or particles due to any cause.

141. Blistering - The irregular raising of a thin layer at the surface of placed mortar or concrete during or soon after completion of the finishing operation, or in the case of pipe after spinning; also bulging of the finish plaster coat as it separates and draws away from the base coat.

142. Chalking - Disintegration of coatings such as a cement paint, manifested by the presence of a loose powder evolved from the paint at, or just beneath, the surface.

143. Delamination - A separation along a plane parallel to a surface as in the separation of a coating from a substrate or the layers of a coating from each other, or in the case of a concrete slab, a horizontal splitting, cracking, or separation of a slab in a plane roughly parallel to, and generally near, the upper surface; found most frequently in bridge decks and caused by the corrosion of reinforcing steel or freezing and thawing; similar to spalling, scaling, or peeling except that delamination affects large areas and can often only be detected by tapping.

144. Drummy area - Unsound areas detected by tapping the concrete surface. Usually associated with subsurface delaminations.

145. Dusting - The development of a powdered material at the surface of hardened concrete.

146. Peeling - A process in which thin flakes of mortar are broken away from a concrete surface, such as by deterioration or by adherence of surface mortar to forms as forms are removed.

147. Scaling - Local flaking or peeling away of the near-surface portion of hardened concrete or mortar; also of a layer from metal.
Note: Light scaling of concrete does not expose coarse aggregate; medium scaling involves loss of surface mortar to 5 to 10 mm in depth and exposure of coarse aggregate; severe scaling involves loss of surface mortar to 5 to 10 mm in depth with some loss of mortar surrounding aggregate particles 10 to 20 mm in depth; very severe scaling involves loss of coarse aggregate particles as well as mortar generally to a depth greater than 20 mm.

148. Weathering - Changes in color, texture, strength, chemical composition or other properties of a natural or artificial material due to the action of the weather.

155. Distortion/movement (unspecified) - Rotation or movement of the element in any direction.

156. Buckling - Failure by lateral or torsional instability of a structural member, occurring with stresses below the yield or ultimate values.

157. Curling - The distortion of an originally essentially linear or planar member into a curved shape such as the warping of a slab due to creep or to differences in temperature or moisture content in the zones adjacent to its opposite faces.

158. Faulting - Differential vertical displacement of a slab or other member adjacent to a joint or crack.

159. Settling - The lowering in elevation of sections of pavement or structures due to their mass, the loads imposed on them, or shrinkage or displacement of the support.

160. Tilting - Movement of a structure in a given direction.

161. Warping - A deviation of a slab or wall surface from its original shape, usually caused by temperature or moisture differentials or both within the slab or wall.

170. Erosion (unspecified) - Progressive disintegration of a solid by the abrasive or cavitation action of gases, fluids, or solids in motion.

171. Abrasion - Erosion resulting from waterborne gravel, rocks, and other debris being circulated over a concrete surface. Abrasion-erosion is readily recognized from the smooth, worn-appearing concrete surface.

172. Cavitation - Erosion resulting from the formation and subsequent collapse of vapor bubbles in a high velocity liquid stream. Repeated collapse of vapor bubbles on or near the surface of concrete result in a rough, pitted surface.

175. Joint sealant failure - Poor performance resulting from improper joint design, greater joint movement than anticipated, improper selection of joint sealant, limited service life, or poor workmanship in construction and sealing of the joint.

180. Seepage (unspecified) - Moisture movement through or around a structure due to any reason.

181. Corrosion - Disintegration or deterioration of concrete or reinforcement by electrolysis or by chemical attack.

182. Discoloration/staining - Departure of color from that which is normal or desired.

183. Exudation - A liquid or viscous gel-like material discharged through a pore, crack, or opening in the surface of concrete.

184. Efflorescence - A deposit of salts, usually white, formed on a surface, the substance having emerged in solution from within concrete or masonry and deposited by evaporation.

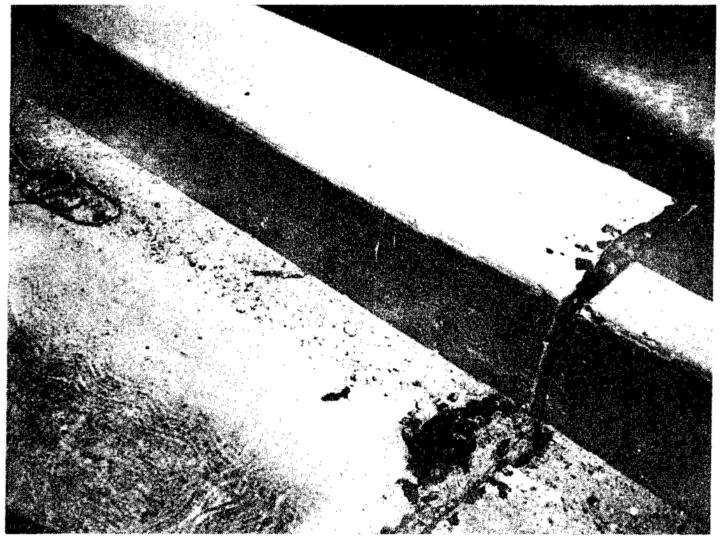
185. Incrustation - A crust or coating, generally hard, formed on the surface of concrete or masonry construction or on aggregate particles.

190. Spalling (unspecified) - A fragment, usually in the shape of a flake, detached from a larger mass by a blow, by the action of weather, by pressure, or by expansion within the larger mass; a small spall involves a roughly circular depression not greater than 20 mm in depth nor 150 mm in any dimension; a large spall may be roughly circular or oval or, in some cases, elongated, more than 20 mm in depth, and 150 mm in greatest dimension.

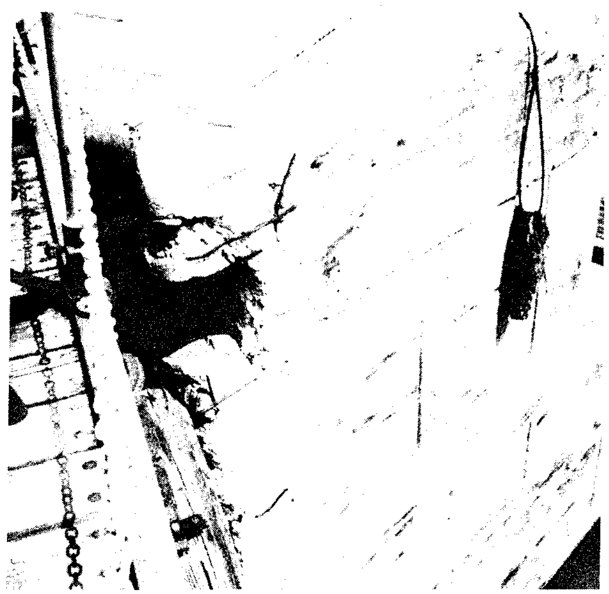
191. Pitting - Development of relatively small cavities in a surface, due to phenomena such as corrosion or cavitation, or, in concrete, localized disintegration.

192. Popout - The breaking away of small portions of a concrete surface due to internal pressure which leaves a shallow, typically conical, depression.

APPENDIX C: TYPICAL CONCRETE DEFICIENCIES CLASSIFIED ACCORDING TO DEGREE OF DAMAGE

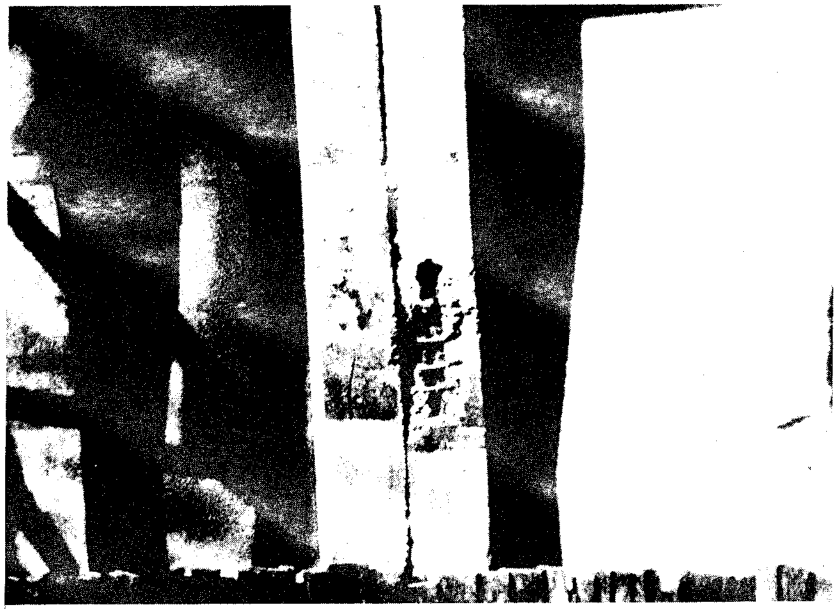


a. Light
(inadequate concrete cover over reinforcing steel)

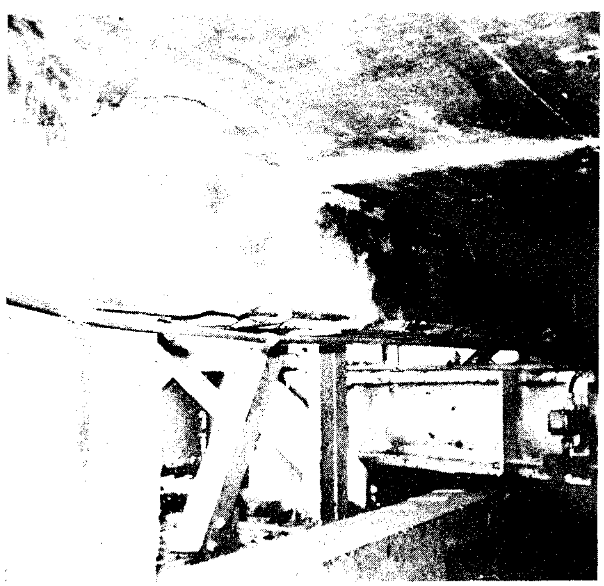


b. Moderate
(inadequate concrete cover over reinforcing steel)

Figure C1. Construction faults (sheet 1 of 2)

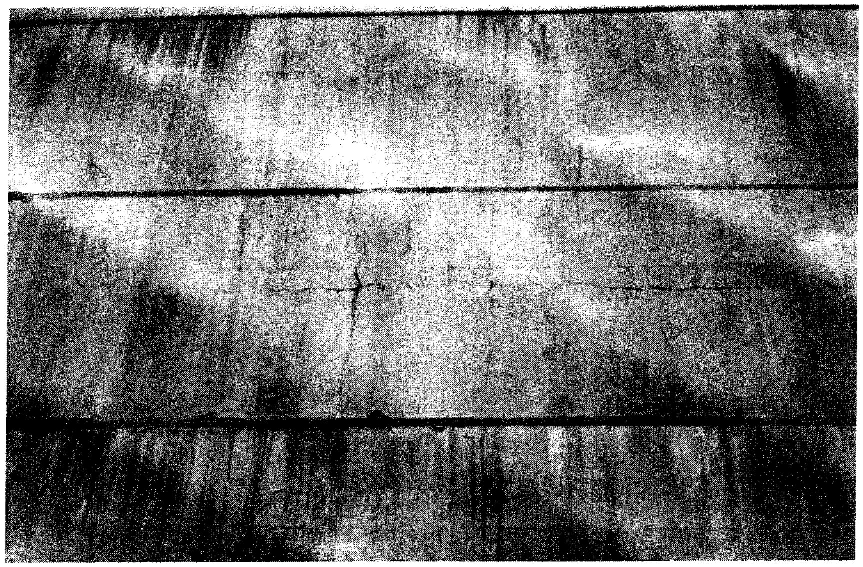


c. Severe
(inadequate concrete consolidation)

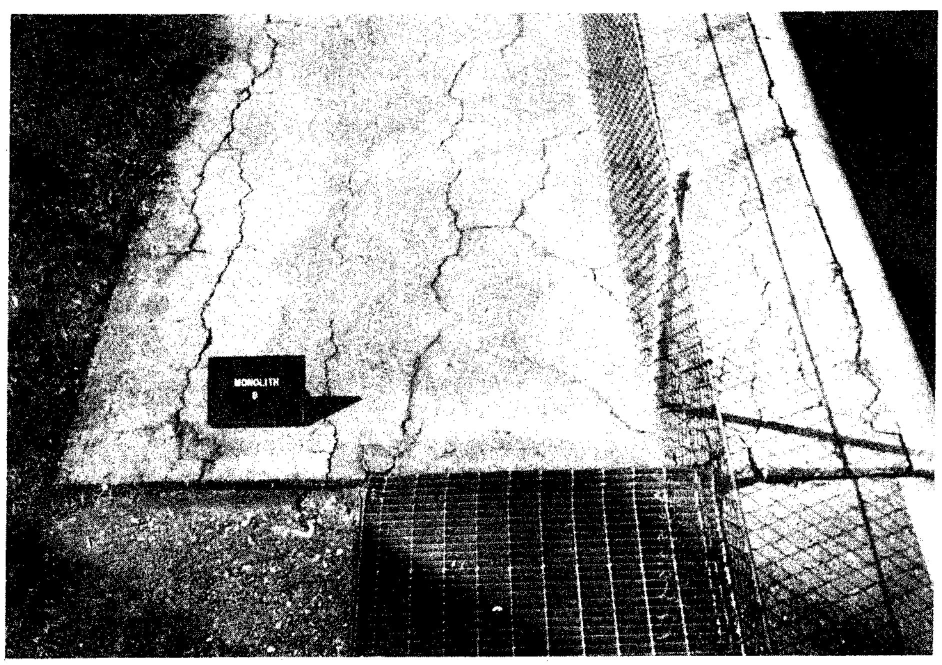


d. Threatens safety of structure
(inadequate concrete cover over reinforcing steel)

Figure C1. Construction faults (sheet 2 of 2)



a. Light



b. Moderate

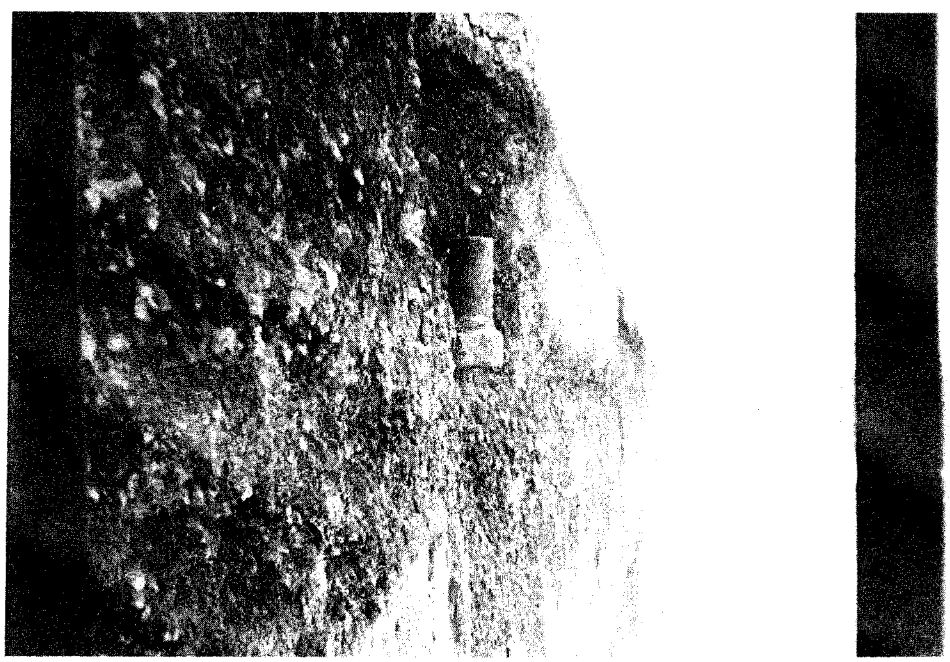
Figure C2. Concrete cracking (sheet 1 of 2)

c. Severe

d. Threatens safety of structure

Figure C2. Concrete cracking (sheet 2 of 2)

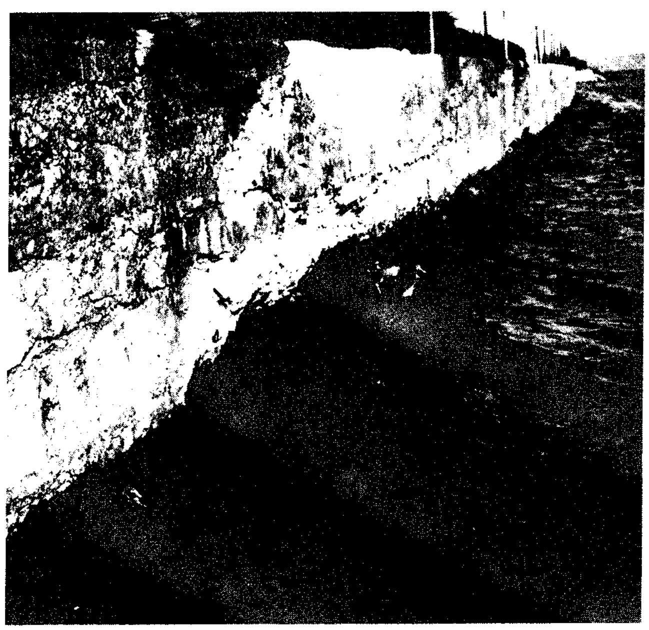
a. Light



b. Moderate

Figure C3. Concrete disintegration (sheet 1 of 2)

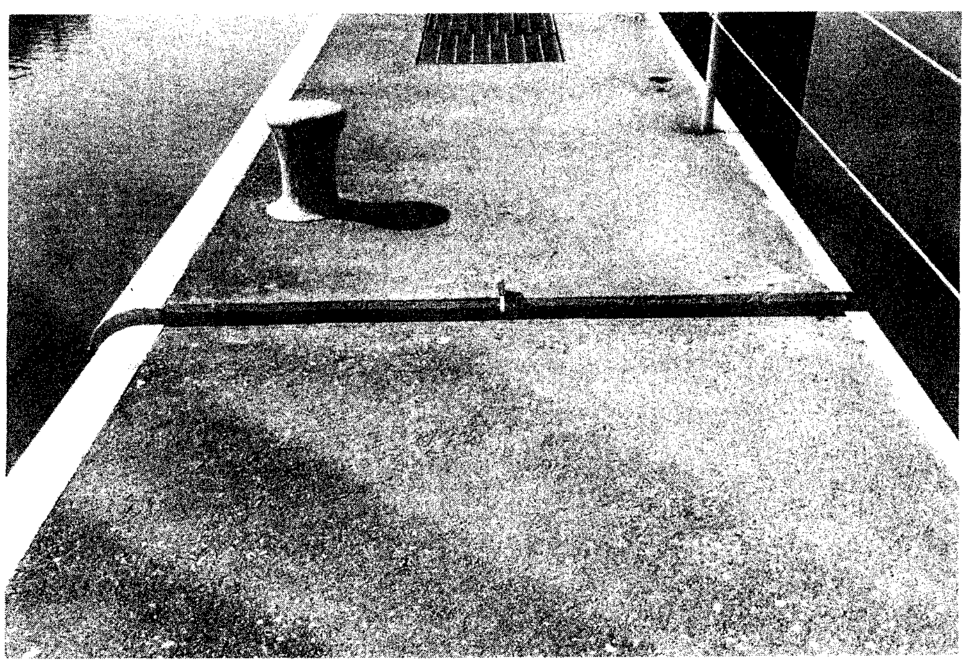
c. Severe



d. Threatens safety of structure

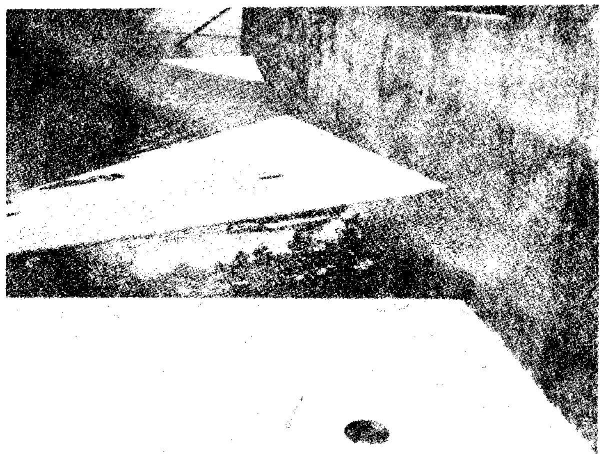
Figure C3. Concrete disintegration (sheet 2 of 2)

a. Light

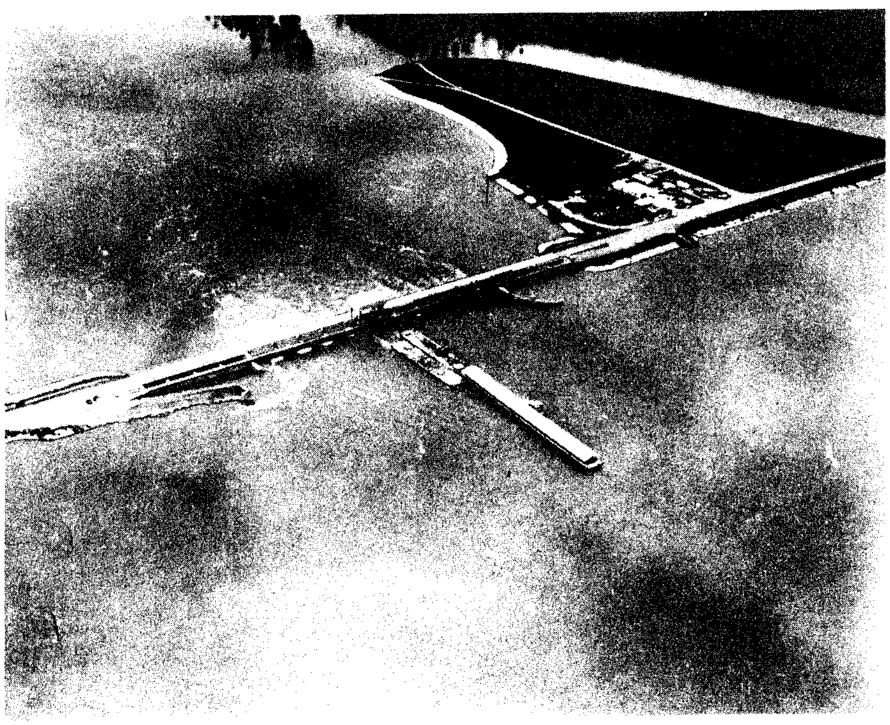


b. Moderate

Figure C4. Distortion or movement (sheet 1 of 2)



c. Severe



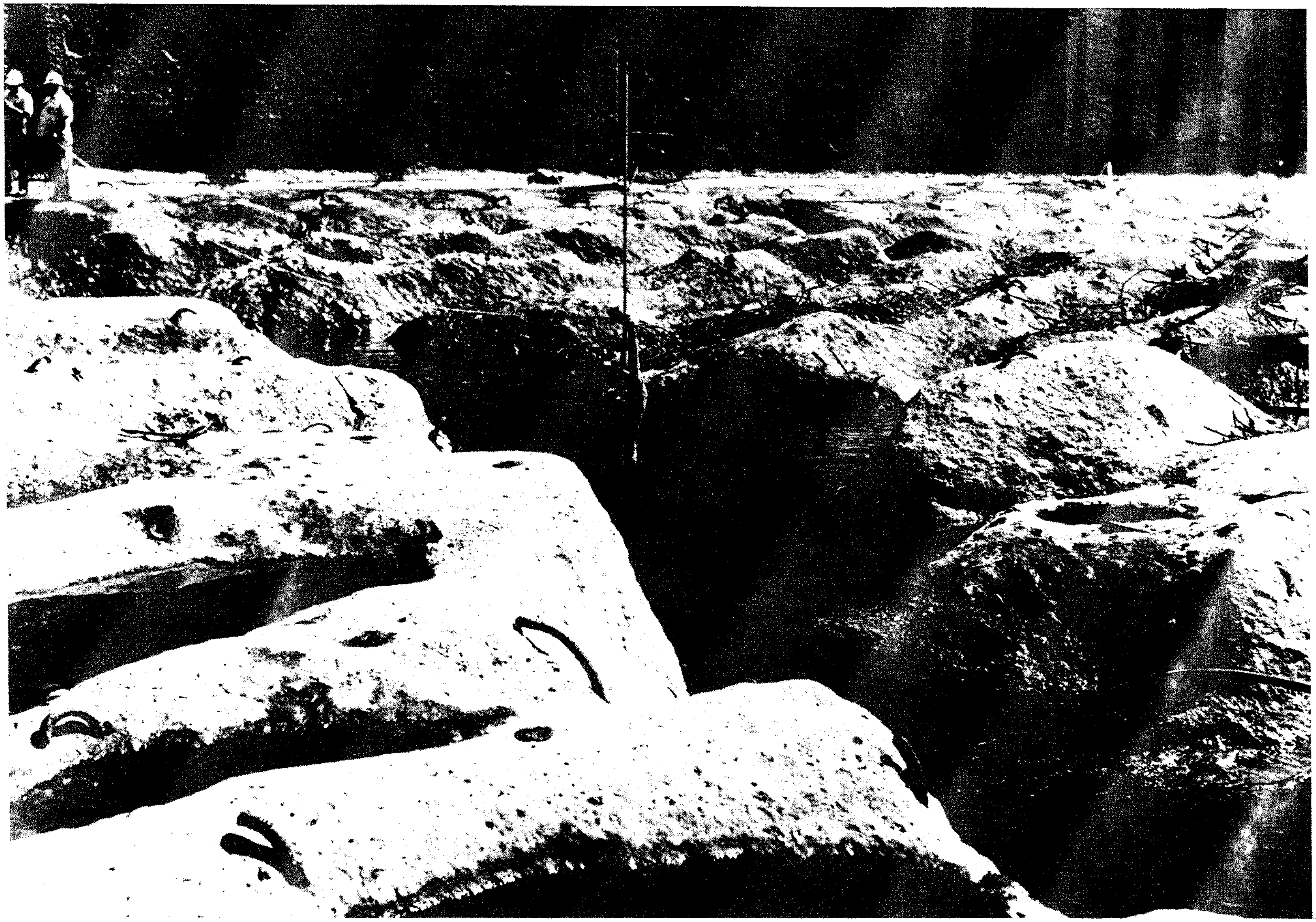
d. Threatens safety of structure

Figure C4. Distortion or movement (sheet 2 of 2)

a. Light

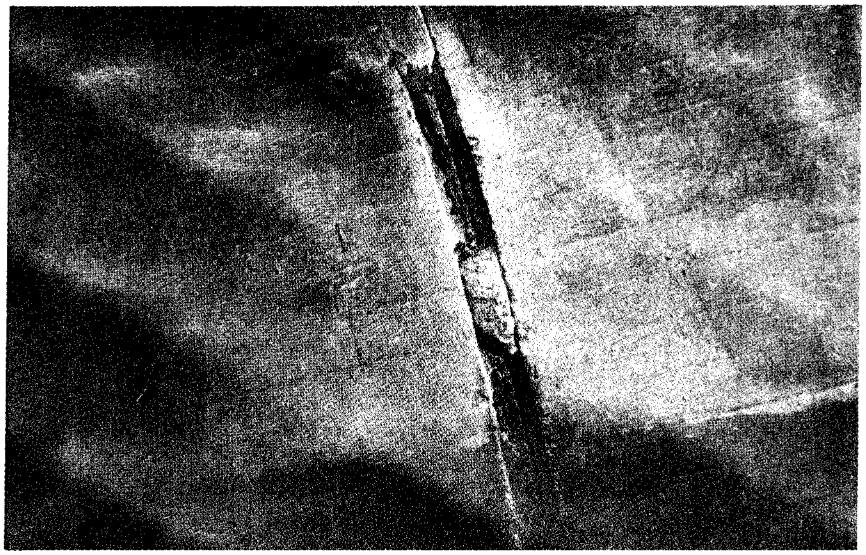
b. Moderate

Figure C5. Concrete erosion (sheet 1 of 2)

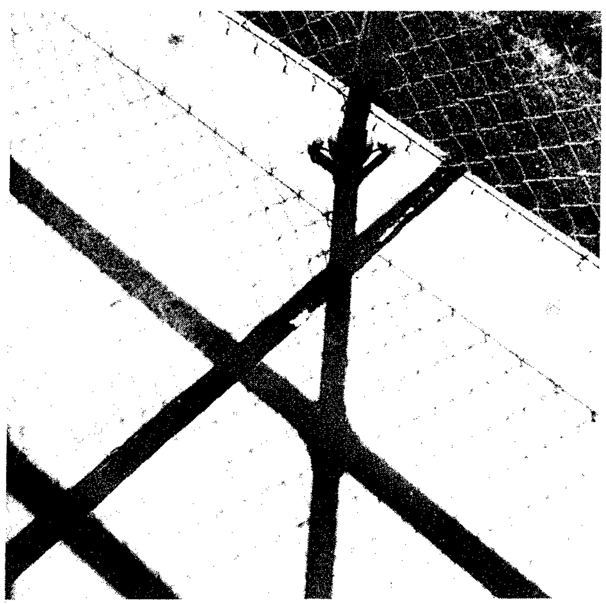


c. Severe

Figure C5. Concrete erosion (sheet 2 of 2)



a. Light

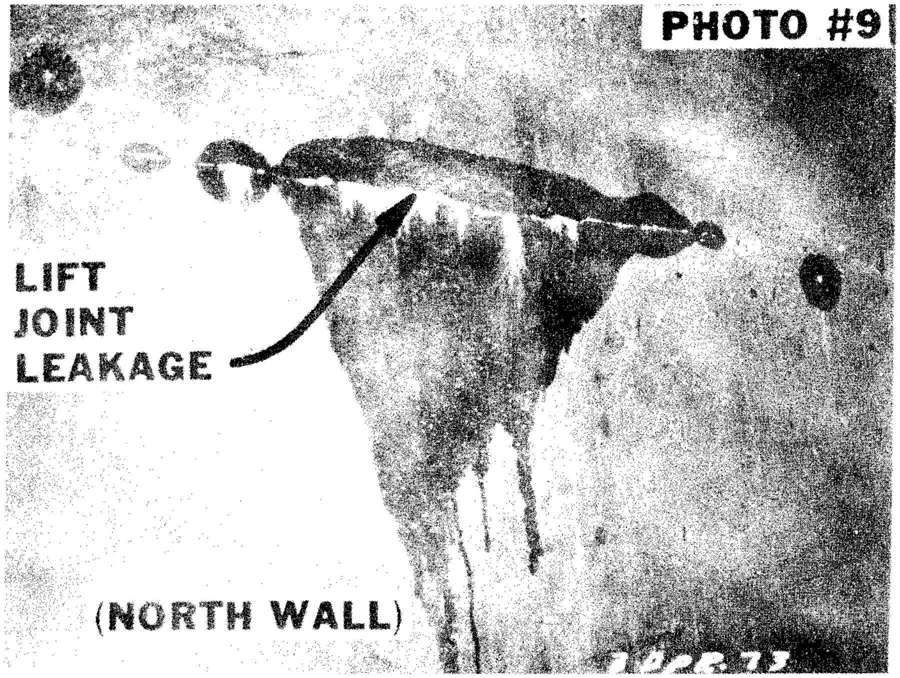


b. Moderate

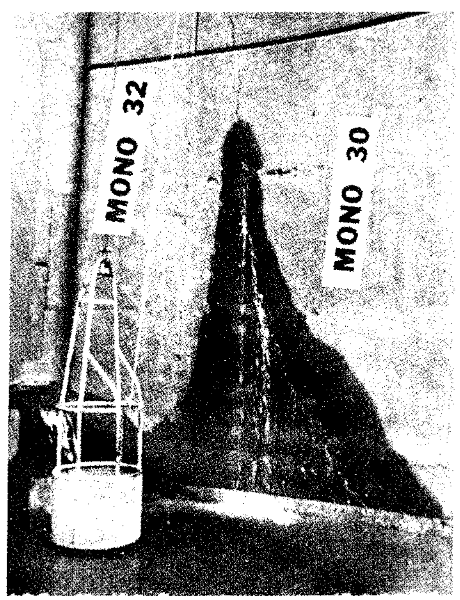
Figure C6. Joint sealant failures (sheet 1 of 2)

c. Severe

Figure C6. Joint sealant failures (sheet 2 of 2)

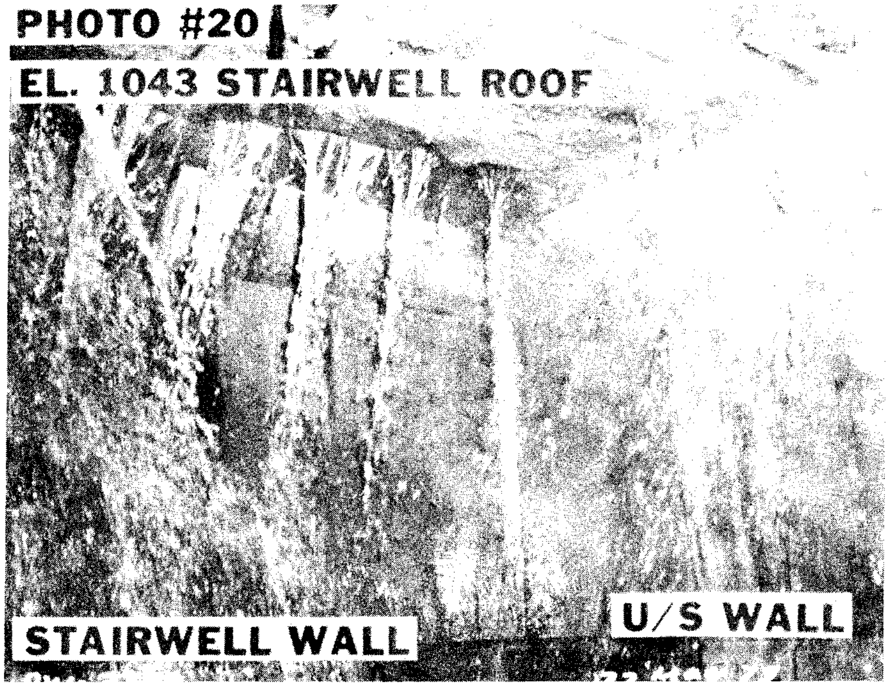


a. Light

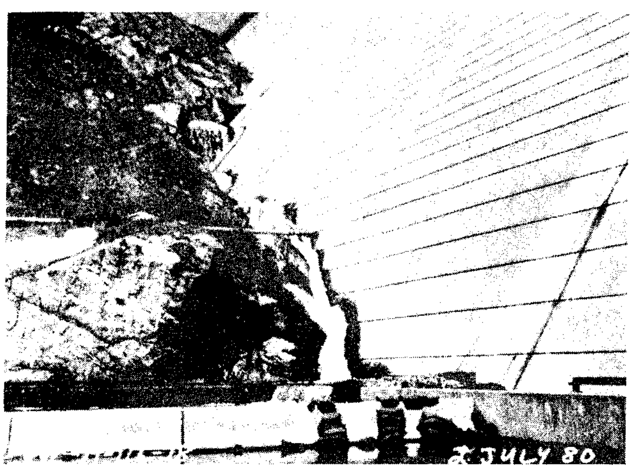


b. Moderate

Figure C7. Seepage (sheet 1 of 2)

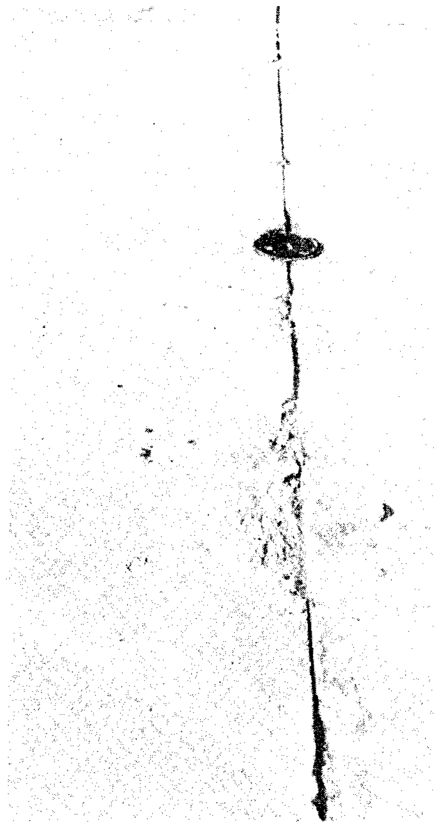


c. Severe

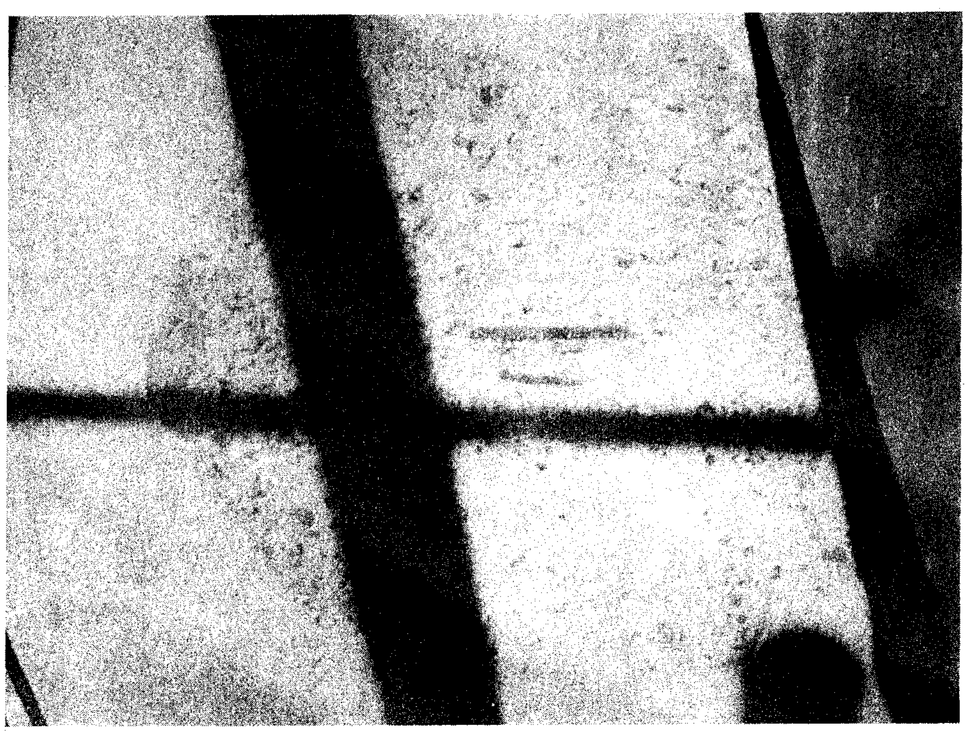


d. Threatens safety of structure

Figure C7. Seepage (sheet 2 of 2)



a. Light



b. Moderate

Figure C8. Concrete spalling (sheet 1 of 2)

c. Severe

d. Threatens safety of structure

Figure C8. Concrete spalling (sheet 2 of 2)